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Environment

Hydrology Branch

Physical Impact of Lake Diefenbaker on its Environment

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PHYSICAL IMPACT
OF
LAKE DIEFENBAKER
ON ITS
ENVIRONMENT

Report No. HYD-6-48

(This report was prepared for the University of Regina relative to a post-graduate degree requirement for the below mentioned preparator and therefore its contents, i.e. conclusions and recommendations, are not necessarily the views of the Hydrology Branch, Water Management Service, Saskatchewan Environment or the Government of Saskatchewan.)

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SYNOPSIS

The Lake Diefenbaker Project which created a large reservoir on the South Saskatchewan River was built between 1958 and 1968. The project has been in full operation since 1969. This report describes the hydrologic impact that this water resources regulation project has had on its physical environment during its first decade of operation. Biological and chemical impacts are not considered.

Streamflow records, sediment records and other literature relevent to this project were studied to determine its impact.

Since the project was constructed as a water control work, it is not surprising that its greatest impact is on the flow regime. By raising the low flow regime and depressing the high flows, the project has reduced the normal annual daily mean flow range of the South Saskatchewan River by a factor of nearly seven. Seasonal flow variations have been reduced but the average annual flow has only decreased by six per cent.

The lake has a retention time of about one year and therefore all incoming sediment is trapped in the reservoir and water released is free of sediment. The sediments deposited will not affect the reservoir in the first several hundred years of operation but the clean water discharged is eroding the downstream channel and will have significant impacts in the near future.

Diversion of water to the Qu'Appelle River has increased and stabilized the flow of that river system by substantially augmenting the flow in dry years and only slightly augmenting the flow in wet years.

The increased level of the water in the South Saskatchewan River valley has raised the ground water levels in the adjacent area and slowed the rate of ground water discharge to the valley in this reach.

The new lake is eroding a new shoreline that has resulted in the need for strict control of shoreline developments.

Minor impacts on climate and river ice conditions are also discussed.

The long-term nature of many of the impacts and recommendations for continued measurement of these impacts are highlighted.

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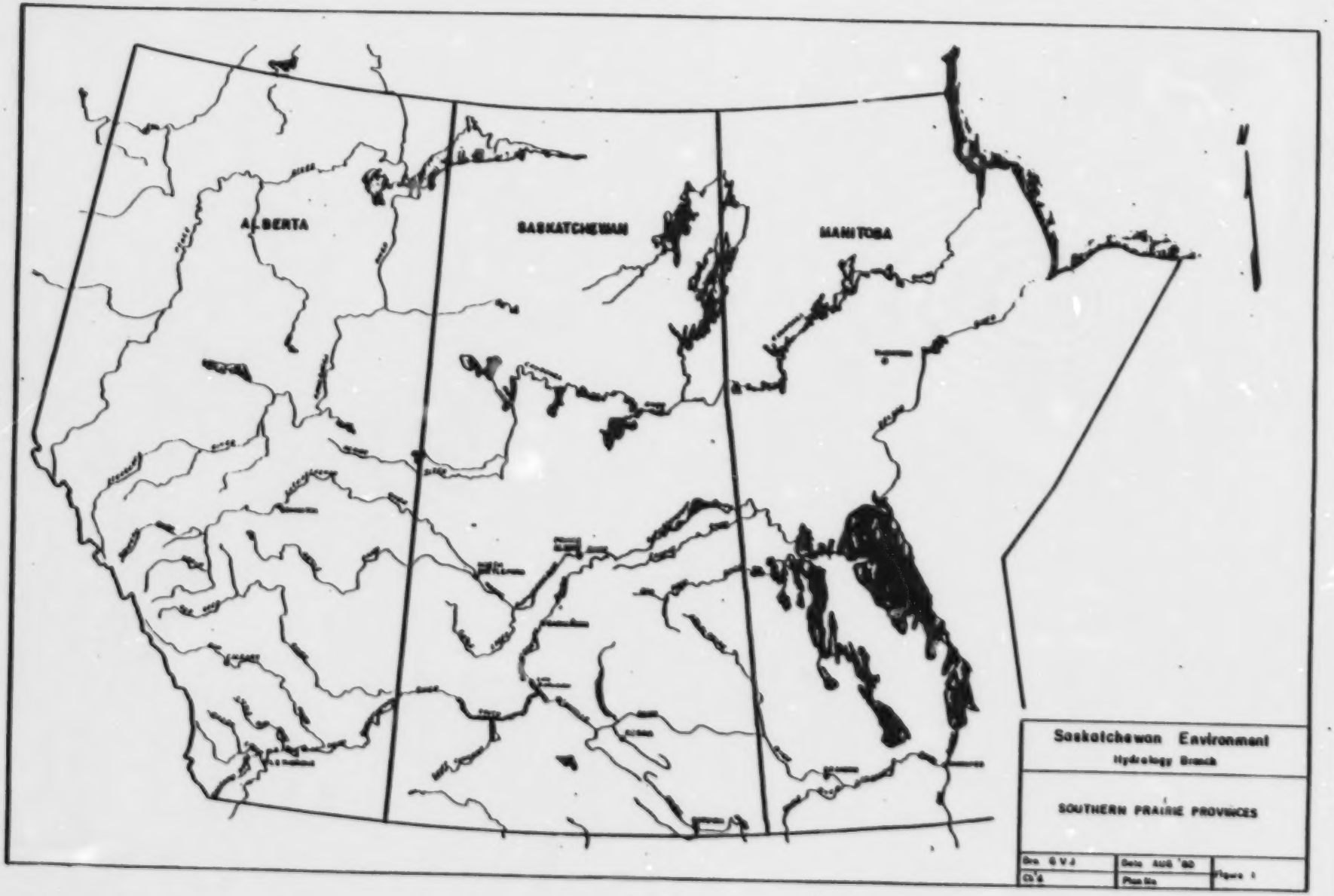
Chapter I

INTRODUCTION

In 1958 the Governments of Canada and Saskatchewan agreed to build the South Saskatchewan River Project to harness the economic potential of the South Saskatchewan River. The project consists of a reservoir created by building Gardiner Dam on the South Saskatchewan River, the Qu'Appelle Valley Dam to control diversion of water into the Qu'Appelle River, the hydroelectric generating station and the diversion works to utilize the water. The dams were built during the decade from 1958 to 1968 and the resulting reservoir which has been named Lake Diefenbaker was first filled during the period from 1964 to 1968. The project has been in full operation since 1969. Figure 1 shows the location of Lake Diefenbaker within the prairie region and Figure 2 shows the configuration of the Lake.

Lake Diefenbaker has a total storage capacity of $9.36 \times 10^9 m^3$ and a live or usable capacity of $4.01 \times 10^9\ m^3$. The area of Lake Diefenbaker when full is 43,000 hectares. Figure 3 describes the area and storage capacity of Lake Diefenbaker.

This very large reservoir has made some vast changes to its physical environment. Many of the changes are obvious such as the conversion of 230 km of river valley into a lake. Some of the changes are less easily quantified and require study to describe.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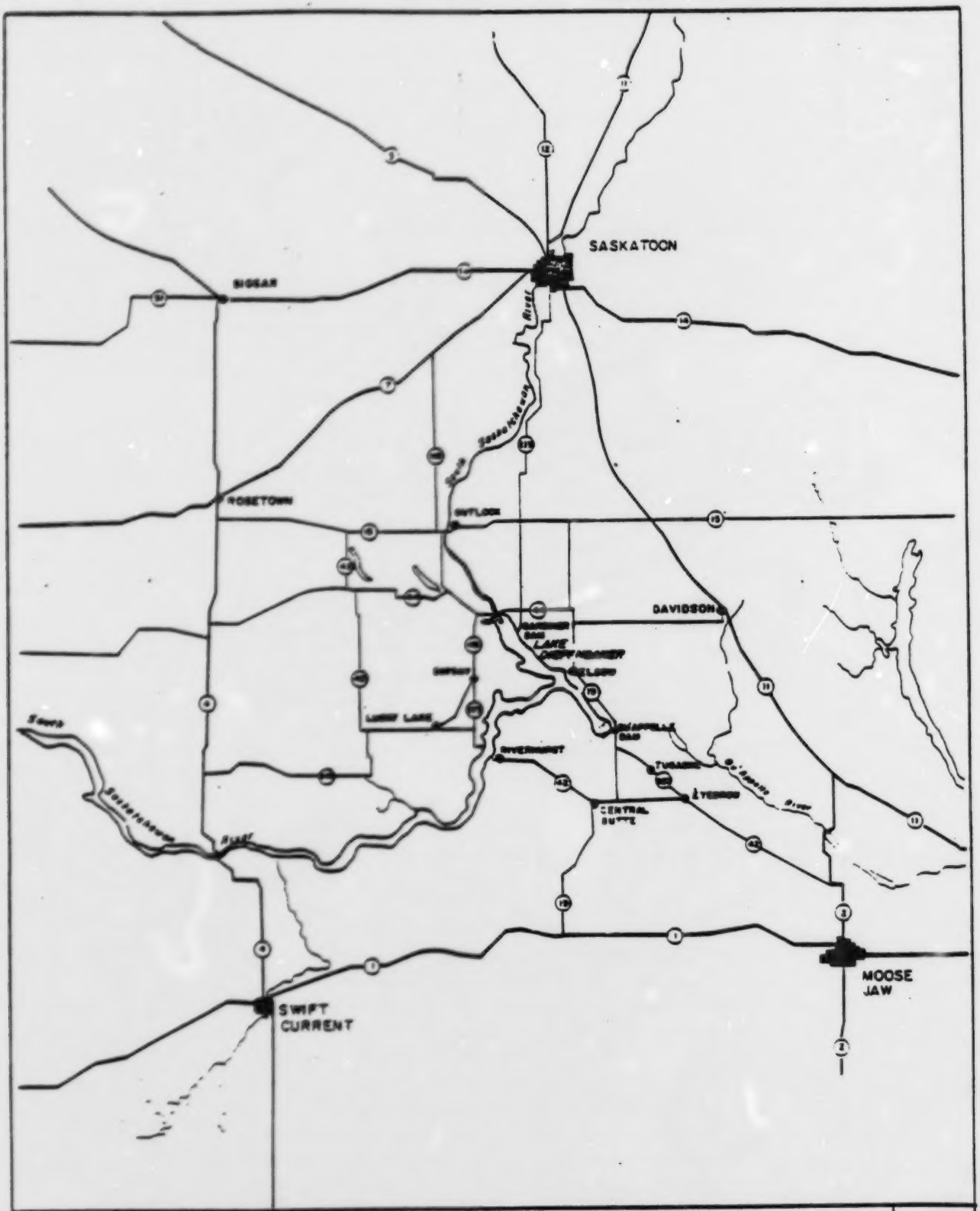
Hydrology Branch
SOUTHERN PRAIRIE PROVINCES
Figure 1



Saskatchewan Environment Hydrology Branch		LAKE DIEFENBAKER	FIGURE 2
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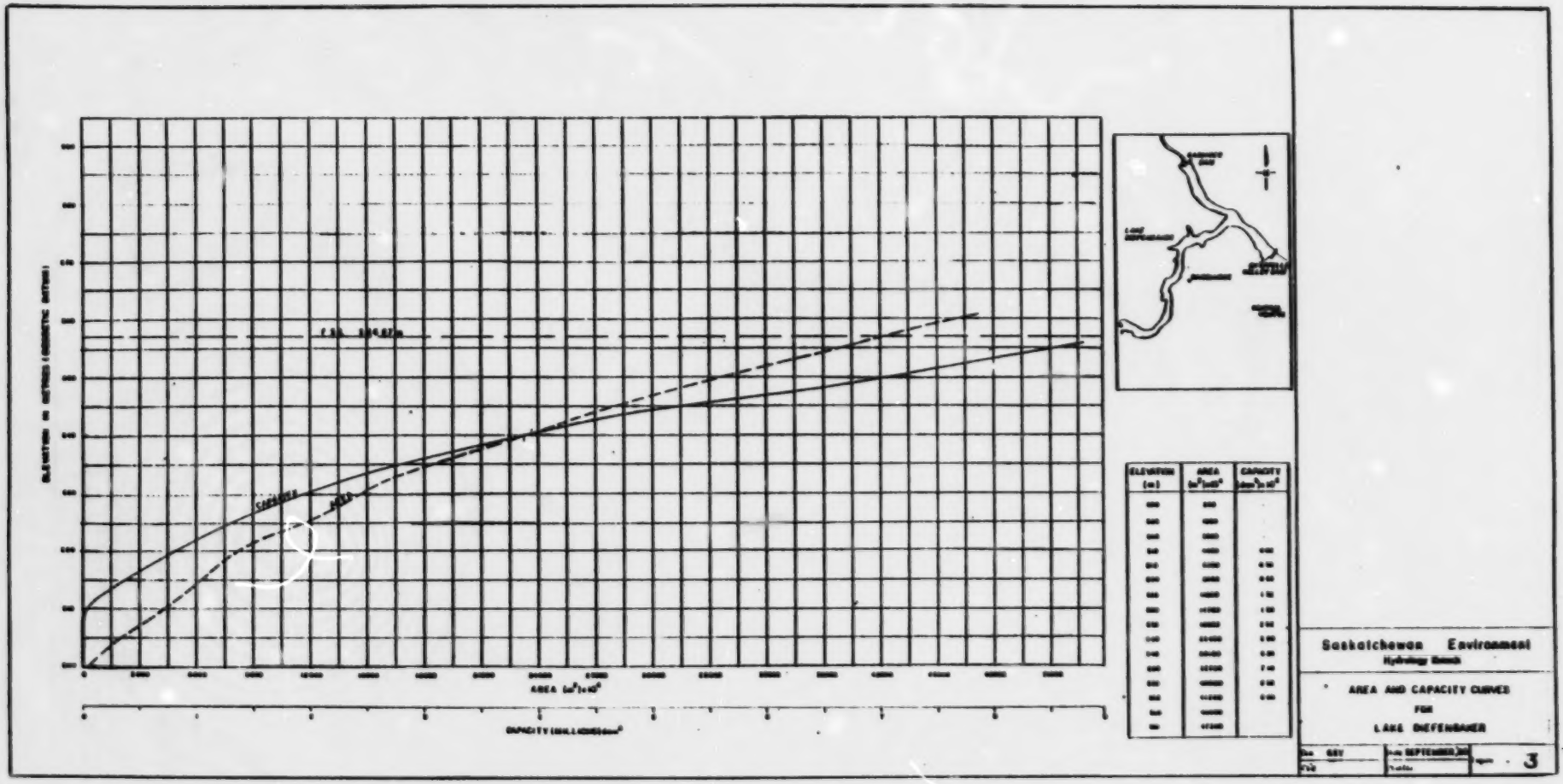

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AREA AND CAPACITY CURVES
FOR
LAKE DIEFENBAKER

3

The purpose of this report is to describe physical changes that the first decade of operation of this project has caused, to attempt to project these changes into the future, to review how management practices might change these impacts and to identify information deficiencies or excesses that require attention.

The chemical, biological and socio-economic impacts of the project will not be dealt with. The impacts studied have been subdivided into the following general categories:

A. SEDIMENTATION AND RIVER DEGRADATION

B. DOWNSTREAM FLOW REGIME

C. QU'APPELLE RIVER FLOW REGIME

D. GROUND WATER

E. SHORELINE EROSION

F. MISCELLANEOUS

Chapter II

STUDY AREA DESCRIPTION

A. GEOLOGIC HISTORY

In order to describe the physical setting of the Lake Diefenbaker project, it is useful to review the geologic history[1] of the region.

About 600 million years ago the surface of the study area was made up of Precambrian bedrocks composed of volcanic lava and similar materials. During the subsequent 500 million years, the area has been subjected to a series of subsidences and inundations by the sea so that layer upon layer of sedimentary rock and evaporite built up during the Palaeozoic and Mesozoic Eras. A thickness of 1500 to 1700 m of stratified sedimentary rock was built up.

Of most significance to the Lake Diefenbaker project is the material of the top 300 m below the surface which has been deposited during the more recent 100 million years. This includes the late Mesozoic and Cenozoic Eras.

During the Late Cretaceous Period, which was the last period in the Mesozoic Era, the present surface bedrock of the study area was deposited. This bedrock is known as the Bearpaw Formation which is composed of alternating layers of marine

deposited clay and silt and non-marine silt and sand. The interbedded layers or members vary in thickness[2] from about 3 m to 35 m. The marine deposits are very fine grained, impervious shales which were formed when fine particles settled out of inland seas. The non-marine deposits are coarse grained, pervious sandstone members which developed as alluvial plains during periods when the region was above sea level. Individual drill holes commonly encounter up to 10 alternating sandstone and shale members in the top 250 m to 300 m of bedrock in the Lake Diefenbaker area.

In the era since the Mesozoic, known as the Cenozoic, two geologic periods, the Tertiary and Quaternary occurred. During the Tertiary period, additional layers of bedrock were deposited over the Bearpaw formation but the glaciations of the Quaternary period scoured these materials away and deposited the glacial till which forms the present overburden and soils in the area. This till is generally in the 10 m to 100 m thickness range and is composed of a wide variety of glacial deposits and glacier related water deposits. Materials ranging from fine clay to boulders is found within short distances.

B. VALLEY HISTORY

The general topographic slope of this region is from the Rocky Mountains east and north toward Hudson Bay. During the period of retreat of the last ice age, between 12,000 to 23,000 years[1] ago, the northeastern route for runoff water and glacial melt water was blocked by the glaciers. With the movement of water to the north blocked,

lakes formed until they overflowed to the lowest available outlet. During the early period of retreat, the water was forced south to the Missouri River system in Montana and North Dakota.

When the ice retreated further, a lower outlet for water coming from southern Alberta and southwest Saskatchewan was exposed. This outlet drained eastward through the present South Saskatchewan River Valley and the Qu'Appelle River Valley into glacial lake Agassiz which covered southern Manitoba. This flow scoured the South Saskatchewan River Valley to Elbow and created the very large Qu'Appelle River Valley and the connection between the two valleys.

After thousands of years, the glaciers retreated north and the river found an even lower outlet to the north. The water of the South Saskatchewan River abandoned the Qu'Appelle River Valley and turned north at the "Elbow," near the Town of Elbow, and joined the North Saskatchewan River near Prince Albert to form the Saskatchewan River which now empties into Lake Winnipeg in Manitoba.

C. SOUTH SASKATCHEWAN RIVER TODAY

Virtually all of the water carried by the South Saskatchewan River originates in the Rocky Mountains and foothills of southern Alberta and northern Montana. The high precipitation rates caused by the steep slopes, the low temperatures and accompanying low evaporation and transpiration rates, and the poor growing conditions which further reduce transpiration losses, result in a high yield of water.

The water is carried out of the mountains, as shown on Figure 1, and eastward toward Saskatchewan by three approximately equal sized rivers:

1. The Oldman River drains the southern segment of the basin carrying water from the mountains of northern Montana and southern Alberta out onto the prairie region.

2. The Bow River drains the central area, west of Calgary. The confluence of the Bow and Oldman Rivers is the upstream end of the South Saskatchewan River which flows a short distance before it enters Saskatchewan.

3. The Red Deer River is the northern tributary. It is similar to the Bow and Oldman Rivers in that it gathers most of its flow in the mountains and foothills then conveys the water onto the prairie. The Red Deer River joins the South Saskatchewan River a short distance east of the Alberta-Saskatchewan border.

Occasional small prairie streams and ground water springs add a small flow to the river as it crosses the prairie region.

The river enters Lake Diefenbaker which occupies 230 km of the original river valley plus about 15 km of the Qu'Appelle Valley. From Lake Diefenbaker the river flows north until it joins the Saskatchewan River. This river carries the water east to Lake Winnipeg in Manitoba.

The climate of the South Saskatchewan River basin controls the seasonal flow pattern. The cold of winter stores most of the precipitation for 6 months as snow and ice so that winter flows are very low. With the onset of spring the snow melts but because of the wide variation of elevation from the prairies to the mountains the melting takes place over a fairly long time period. The prairie runoff occurs in late March and early April. The mountain snowmelt runoff progresses through late April, May and early June. May, June and July are the high precipitation months of the year, compared to the other months, so that rainfall runoff overlaps the recession of the snowmelt runoff and the peak flows typically occur in June.

Through the fall, with reducing precipitation and the snowmelt complete, the flows recede toward the low winter values.

D. HUMAN INFLUENCE ON FLOWS

Water development in the South Saskatchewan River Basin has grown steadily since the beginning of the century. Water use for irrigation and evaporation from reservoirs significantly deplete the annual flow. Storage of water in reservoirs for hydroelectric generation changes the flow pattern from season to season. A considerable portion of these man-made influences occur upstream of Lake Diefenbaker, in Alberta.

The Prairie Provinces Water Board monitors water use for administration of a Master Agreement on water apportionment. During some periods, water use in Alberta has exceeded 50 per cent of the

natural flow but on an annual basis the depletion is considerably below this amount. Under the terms of the Apportionment Agreement, Alberta could eventually use up to 50 per cent of the annual natural flow of the South Saskatchewan River.

Although this report only analyzes the impact of Lake Diefenbaker, it is useful to note that the inflows have already been substantially manipulated before they reach Lake Diefenbaker.

E. LAKE DIEFENBAKER

Lake Diefenbaker was formed by construction of a 65 m high earthfill dam, Gardiner Dam, across the South Saskatchewan River Valley 100 km upstream of Saskatoon. Since the lake that was formed would have spilled east down the Qu'appelle River Valley, the project also included the Qu'Appelle Valley Dam which is a 25 m high earthfill structure.

Gardiner Dam includes five gated conduits, three of which are harnessed by hydroelectric turbines. Under normal conditions, all releases of water to the South Saskatchewan River are made through these turbines. For extreme floods when the turbines are inadequate, there is a gated concrete chute spillway to pass excess flows.

The Qu'Appelle Valley Dam includes a gated conduit which permits controlled releases of water from Lake Diefenbaker into the Qu'Appelle River.

Lake Diefenbaker floods 43,000 hectares of the South Saskatchewan and Qu'Appelle River valleys. When full, the depth of water varies from 60 m at Gardiner Dam to zero 230 km upstream on the South Saskatchewan River. The lake has a total capacity of 9.36×10^9 m^3 of which 4.01×10^9 m^3 is usable. Figure 3 shows how the area and storage capacity vary with surface elevation.

This project was built to meet the following major objectives:

1. water supply for a large area of dry land whose productive capacity could be greatly improved by the addition of a firm supply of water for irrigation;

2. hydroelectric energy generation;

3. flow regulation for flood control, water supply, effluent dilution and downstream energy generation;

4. water supply to urban, rural, recreation and wildlife users along the Qu'Appelle River system; and

5. recreation, wildlife and fishery enhancement.

Chapter III

PREDICTED IMPACTS

A. GENERAL

Although this project was planned and constructed before the age of formalized environmental impact assessments, much effort was expended during the planning and construction years to predict some of the impacts that this project would have on its environment.

B. SEDIMENT REGIME

There are two aspects to sediment transport in a river that are important to the planning and design of a water storage reservoir. The most obvious is the sediment build-up in the reservoir which may be a significant limitation to the useful life of the the project. The second, more subtle impact, is the impact of the lack of sediment in the water leaving the outlet works, on the downstream river.

During the planning of Lake Diefenbaker, two calculations of potential sediment build-up in the reservoir were completed.

The first was contained in a 1952[3] engineering report on theproposed project. That study used the results of 482 suspended sediment samples taken during 1948 and 1949 to estimate the sediment flow of the South Saskatchewan River at Outlook and to relate that sediment flow to the water flow of the river. This relationship was then applied to the recorded water flows of the river from 1911 to 1943 and an average annual sediment load of 15.95×10^9 pounds or 7.2×10^9 kg

was calculated. Using an estimated density of 1340 kg/m^3, the average annual volume of sediment deposited was estimated to be 5.48 x 10^6 m^3. The reservoir configuration under consideration at that time had 4.93 x 10^9 m^3 of dead storage and it was assumed that the sediment would accumulate in this dead storage volume. With this assumption it would take 900 years for the dead storage to be used up. It was concluded that sedimentation would not be a problem.

In 1962[4] a more detailed evaluation of sedimentation was undertaken. It was estimated that the average annual sediment deposition would be 7.4 x10^6 m^3 which is larger than the earlier study but still small compared to the reservoir volume. Analysis of the probable location of the delta formation indicated that it could have some impact on the live storage volume but that the impact would be small, about 10% in the first 100 years.

Although sedimentation was not expected to be a problem within the planning life of Lake Diefenbaker, a program to measure sediment build-up at selected cross sections in the reservoir was started in 1964, before the reservoir began to fill.

The second sediment question, that of scour downstream of the impoundment, was of concern for project design. The hydraulic design and safety of engineering components of the dam such as the spillway, conduit outlets and power station require a knowledge of tailwater conditions. The energy contained in water rushing down the spillway

must be dissipated within the concrete stilling basin through violent turbulence. If the tailwater elevation reaches a lower value than the design provided for, this turbulence will occur downstream of the concrete stilling basin and might undercut the downstream components of the dam and damage the structure. The hydraulic design of the dam, therefore, included allowance for the potential degradation of the river channel downstream of Gardiner Dam. For the design flood[3], which was the 1:1000 year event or 7500 m^3/sec, the spillway elevation was set 2.1 m lower than the historical tailwater rating curve required.

A program to measure this impact from Gardiner Dam to Saskatoonwas established and results are described later in this report.

C. FLOW REGIME

During the planning of the Lake Diefenbaker project water supply simulations[3] were completed. These calculations used the flows of the South Saskatchewan River, as measured prior to dam construction, to simulate how the project was expected to be operated. These simulations were aimed at determining how well the project would meet anticipated water supply needs. Expected flows downstream of the project were developed.

It was found that the average annual natural flow of the South Saskatchewan River was 8.8×10^9 m^3. After allowing for potential upstream uses of 3.4×10^9 m^3, the average annual supply of water to

Lake Diefenbaker would be 5.4 x 10^9 m^3. The monthly distribution of the inflow from 1911 to the time of the study was estimated and the ability of the project to meet water uses and to generate hydroelectric power was determined.

It was determined that all irrigation and municipal demands for water could be met and that there would be sufficient water for a firm power supply of 3.3 x 10^6 MWH per year, with larger energy production in most years.

It was determined that the majority of the summer flow of the river would be stored in the reservoir for release in winter when the electrical energy generated by the releases would be most useful to Saskatchewan.

D. QU'APPELLE RIVER FLOW REGIME

Figure 1 shows the Qu'Appelle River connected to the Qu'Appelle Arm of Lake Diefenbaker. This feature of the project is one of the reasons for the location of the Lake Diefenbaker project since supplying water to users in the Qu'Appelle River Basin was one of the objectives of the project. Water supply studies based on simulations of monthly mean flows for the period 1921 to 1950 were completed for a wide variety of operation and diversion alternatives.

The first study was completed by the South Saskatchewan Reservoir Development Commission[5] in 1962 to determine how large the outlet

works through the Qu'Appelle Valley Dam should be to accommodate future needs in the Qu'Appelle River Basin. It was estimated that average annual water demands would be 101 x 10^6 m^3 by 1970 and 148 x 10^6 m^3 by the year 2000. The largest demands resulted from the amount of water that could be needed to offset evaporation losses from the recreation lakes. Irrigation, wildlife and municipal demands were also considered. Diversion of water at these rates would satisfy all demands for water and would require substantial increases in the carrying capacity of the Qu'Appelle River. The average monthly distribution of this water is illustrated in Table 1.

The second study[6] described the importance of water recreation in the Qu'Appelle River Valley and pointed out the need for Lake Diefenbaker water to maintain the water level of Last Mountain Lake, the largest lake in the Qu'Appelle River system, if it is to serve as a recreation base. Quantities of water from the earlier study were considered. This study indicated that Lake Diefenbaker water could significantly enhance recreation opportunities in the Qu'Appelle Valley.

The third study[7] was completed by the Saskatchewan Water Resources Commission in 1965 and it expanded on the analysis[5] of operation alternatives that were studied in 1962. In particular, this study looked into the impact that a limited channel capacity would have on diversion of water to the Qu'Appelle River. It was found that most of the water needs in the Qu'Appelle River Valley could be met if the diversion capacity were limited to 11.3 m/s. Depending on the

operating assumptions, the average annual diversion was found to vary from 80 x 10^6 m^3 to 87 x 10^6. The limited diversion capacity and the slightly more efficient use of local Qu'Appelle River water in this study resulted in slightly lower diversion quantities than the 1962 study.

Table 1

MONTHLY DISTRIBUTION OF QU'APPELLE RIVER DIVERSIONS AS PROJECTED IN 1962

Monthly Mean Flows (1921-50) in millions of cubic metres

Month	Circa 1970		Circa 2000	
	Volume	%	Volume	%
January	0.0	0.0	0.0	0.0
February	0.0	0.0	0.3	0.2
March	0.0	0.0	2.4	1.6
April	2.5	2.5	6.3	4.3
May	12.3	12.2	23.0	15.5
June	23.4	23.2	30.0	20.3
July	27.0	26.7	36.0	24.4
August	24.7	24.5	32.0	21.6
September	7.4	7.3	10.4	7.0
October	3.7	3.6	7.5	5.1
November	0.0	0.0	0.0	0.0
December	0.0	0.0	0.0	0.0
TOTAL	101.0	100.0	147.9	100.0

E. GROUND WATER

The South Saskatchewan River Valley is substantially below the surrounding area and ground water discharges toward the valley. The regional water table surrounding Lake Diefenbaker is above the maximum lake level so that ground water should eventually discharge to the lake as well, but this raised discharge point will create backwater through the ground water regime. This should result in higher water table levels in the region surrounding the reservoir. There should be a period of instability as the ground water regime adjusts to the new situation.

This impact was anticipated before Lake Diefenbaker was filled and a cross section of ground water observation wells and piezometers was installed in the Riverhurst area to record the impact of filling Lake Diefenbaker. In 1968, R. O. Van Everdingen[8], described the installation of this observation system. The piezometers were installed in the sandstone aquifers of the upper Cretaceous formations which underlie the reservoir in the period from 1962 to 1964. The piezometers monitor a cross section roughly 3 km south of the river to 6 km north of the river approximately parallel to Highway 42 at the Riverhurst Ferry.

As well as installing instrumentation to monitor the changes, electrical model studies were completed to predict the changes that might occur. It was estimated that in the Riverhurst area there was inflow of about 3×10^{-6} m^3/s per metre of river valley prior to Lake Diefenbaker.

This water came from the glacial drift plus bedrock discharge to the valley.

It was also estimated that the raised water level in the valley, due to the new lake, would back up the inflow causing reduced gradient toward the valley, a reduction in the subterranean drainage area and more movement of water parallel to the valley so that the inflow to the valley would be reduced. A rough estimate of the reduction at Riverhurst Ferry was 50 per cent[8]. A similar impact would occur throughout the length of Lake Diefenbaker with slightly more impact closer to Gardiner Dam where the lake is deepest and zero impact at the west end of the lake where no water level change was expected.

The raised water table in the glacial drift would make shallow wells more productive and cheaper to construct and operate. It might cause more water logging and salinity of areas where the water table approaches the ground surface.

The raised piezometric pressure in the deep aquifers would result in greater discharges from these aquifers at other outlet points, particularly downstream of Gardiner Dam.

F. SHORELINE EROSION

Lake Diefenbaker is a large new body of water placed in a relatively steep sided river valley. In such a situation, a new lake shore environment is created. The planning and design of the project

recognized this factor in two ways. First, the "take line," which encompasses the lands purchased for the right-of-way of the lake, was placed a generous distance beyond the area of land that would be flooded directly by the lake. Secondly, regulatory restrictions were placed on land use in the vicinity of the reservoir to prevent developments that could be incompatible with the erosion danger around this new shoreline.

Mollard[9], in 1961, prepared a general description of anticipated shoreline development and in a number of site specific reports, prepared in 1963 and 1964, he expanded on this topic. The following paragraphs briefly summarize the expected impact of the new lake on its shoreline.

The slope of the shore at any given location was expected to influence the rate of erosion because the waves would break before reaching the shore and dissipate their energy without effect on flat or gentle slopes. At locations of steep slope where the wave energy would reach the shore and be dissipated in a short distance, erosion would result. The valley slopes generally had a 1:15 slope with local slopes much steeper. This slope was considered to be too steep to be stable as a lake shore, so significant erosion was expected as the lake creates new flat sloped beaches.

The shoreline configuration was expected to influence the rate of erosion. Points and peninsulas extending into the lake would erode

most rapidly and since the material eroded would move laterally off the points, they would not develop protective beaches to stabilize the shore. Bays and inlets would be protected from heavy wave action and would accumulate littoral drift so erosion would be slowed. Fetch and prevailing wind direction influence the magnitude of wave action and hence the erosion rates. The physical make-up of the beach material affects the form and rate of erosion. Small grained soils will be easily transported by wave action and require a much flatter beach slope for stability than sand or cobbles. It was also noted that cohesive soils would form cliffs as a result of erosion.

As a result of the expected erosion, it was recommended that the reservoir "take line" should be 90 to 180 m inland from the full supply level and that land uses should be controlled all around the reservoir. Because erosion is difficult to predict, it was suggested that it should be monitored by air photography after the reservoir was filled and operated.

G. OTHER PHYSICAL IMPACTS

Physical impact projections on other segments of the environment are not available in the planning documents for the project.

Chapter IV

SEDIMENT REGIME

A. GENERAL

As mentioned earlier, Lake Diefenbaker, with its large storage volume, was expected to precipitate all the sediment load of the South Saskatchewan River and to discharge clear water which could scour the downstream river. Measurement programs to monitor both deposition and downstream scour were established and have been carried out since 1964.

B. SEDIMENT TRAP EFFICIENCY

Sediment data[10] is available at various locations in the study area for the period from 1962 to 1976. The monthly total sediment loading for points in the study area are summarized in Appendix B. The annual values are summarized in Table 2.

Prior to construction of Lake Diefenbaker the South Saskatchewan River through its lower reaches was fairly stable with respect to sediment. It carried a fairly large amount of sediment but, as with the flow regime, the river was mainly a conveyance mechanism rather than contributing or collecting sediment in this reach.

Comparison of the 1962 and 1963 data for the South Saskatchewan River near Lemsford and at Saskatoon indicates a gain of 3.5 per cent then a loss of 9.3 per cent in the suspended loading. Considering that the measurement of suspended sediment is an imprecise process, this

TABLE 2

ANNUAL SUSPENDED SEDIMENT LOADING

10^6 kg

Year	S. Sask. R. at Lemsford	S. Sask. R. at S'toon	Swift Current Creek	Red Deer R. Near Bindloss	S. Sask. R. at Hwy. 41	Total at Alberta Border
1962	1645.5	1703.5	-	-	-	-
1963	4438.6	4060.0	-	-	-	-
1964	6996.3	3758.3	-	-	-	-
1965	8819.6	2468.0	2.0	-	-	-
1966	4743.1	1519.8	27.7	-	-	-
1967	11448.6	404.0	153.0	2413.0	7487.0	9900.0
1968	2413.7	92.0	2.1	843.8	1180.8	2024.6
1969	9582.2	1947.3	85.0	4715.5	4556.4	9271.8
1970	5119.5	229.0	104.4	2927.2	2697.8	5625.0
1971	-	170.7	96.2	4734.8	2347.0	7081.0
1972	-	-	1.4	1597.4	4725.3	6322.7
1973	-	-	-	1573.3	720.8	2294.1
1974	-	-	-	5289.6	4101.0	9390.6
1975	-	-	-	1144.7	7464.0	8608.7
1976	-	-	-	887.7	1300.8	2188.5

comparison confirms that there was little net scour or deposition in this river reach before construction of Lake Diefenbaker. Comparison of the sum of the Red Deer River near Bindloss and the South Saskatchewan River at Highway 41, both locations are a short distance west of the Alberta-Saskatchewan boundary, with the downstream Lemsford measurements for the 1967 to 1970 period further confirms the conveyance character of the river in the study area. Over the four years of overlapping record the difference in suspended sediment has averaged 9.4 per cent with the downstream Lemsford station having the slightly larger sediment load.

The data for Swift Current Creek indicates that the small local tributaries contribute some sediment but not a very significant quantity compared to the total.

When construction of Gardiner Dam began to retard the flow of the South Saskatchewan River in 1964, the sediment load comparison between Lemsford and Saskatoon quickly diverged. The proportion dropped to just over 50 per cent in 1964 and to just over 25 per cent in 1965 and 1966. In 1967 the lake was not quite full but it was large enough that all the incoming sediment was trapped. The Saskatoon sediment load was only 4 per cent of the inflow sediment load and that sediment originated in the river between Gardiner Dam and Saskatoon. Measurements of suspended sediment at the outlet of Gardiner Dam show no detectible sediment load. Since these measurements consistently showed zero values, they were not continued on a regular basis. The

sediment load at Saskatoon continued to show a small portion of the original natural loading until 1971 when the station was discontinued.

Within the limits of measurement accuracy Lake Diefenbaker is a 100 per cent efficient sediment trap. All the suspended sediment entering Lake Diefenbaker with its inflowing water is deposited in the lake. The outflowing water is clear of sediment until it begins to scour material from the river downstream of the dam.

C. RESERVOIR INFILLING

Using the data in Table 2 for Lemsford from 1962 to 1970 and at the Alberta-Saskatchewan Border from 1970 to 1976 the average annual inflow of sediment from the South Saskatchewan River to Lake Diefenbaker is 6072.8 x 10^6 kg and the standard deviation is 3009.3 x 10^6 kg. There will be a small additional inflow of sediment from the local tributaries and the South Saskatchewan River carries some bed load which is not measured. There is also erosion around the shoreline due to wave action that is contributing to reservoir infilling. Stichling[11] suggests that bed load generally adds between 5 and 20 per cent to the suspended sediment load. In the relatively slow moving South Saskatchewan, it can be expected that the bed load is in the low end of this range. The measured data on Swift Current Creek, which is the largest local tributary, suggests that this source of sediment is likely one to two per cent of the total. The bank erosion was rapid in the early years but will not be a major long-term contributor to reservoir infilling. It is estimated that all these

minor sources will add 10 per cent to the sediment infilling at Lake Diefenbaker.

Since Lake Diefenbaker retains all inflow sediment, the average annual sedimentation is about 6.7×10^9 kg per year.

As this sediment material settles in a reservoir, there is very little force to compress it so its initial density is very low. As time passes and additional sediments accumulate, the lower material will be compressed and compacted. Based on an emperical analysis of approximately 200 measurements of sediment density in large reservoirs in the United States, Lane and Koelzer[12] proposed that the density of reservoir sediment deposits would increase with time according to to the following function:

$$W = W_1 + K \log_{10} T$$

Where W is the density of deposits after time T,

W_1 is the density of deposits after one year,

K is a constant that varies with particle size, and

T is time in years.

The values of the constant K are largest for the small particle sizes and reduce to zero for particles larger than silt. Typical W_1 values, suggested by Lane and Koelzer, range from 1500 kg/m^3 for sand to 1200 kg/m^3 for silt and 740 kg/m^3 for clay. K values vary from 0 to 256.

In 1972, the density of sediment deposits at selected locations in Lake Diefenbaker were measured.[13] Three measurements taken in the

main reservoir averaged 720 kg/m3. Grain size analysis indicated that these samples were mainly silt and clay materials. Since these deposits were laid down from 1966 to 1972, their average age was 3 years. Since these deposits are fairly small grained use of high K, say 150, in the Lane Koelzer equation is justified. The Log_{10} of 3 is only .48, so that even this high K value has limited impact on the calculations, 70 kg/m^3 on the density. The density at the end of the first year was likely about 670 kg/m^3.

After 100 years or 1000 years, the density would increase by 300 and 450 kg/m^3. For convenience, it was assumed that an averaged sediment density of about 1000 kg/m^3 could be used. The thickness of deposits, mineral composition of sediments and reservoir operations can have slight effects on this density, however, this approximation is sufficient for this analysis.

When applied to the 6.7×10^9 kg per year, sediment inflow, it was found that on average the volume of Lake Diefenbaker will be reducing 6.7×10^6 m^3 per year or about 0.07 per cent of the total original 9.36×10^9 m^3 volume. This confirms the planning estimates which projected that Lake Diefenbaker has an approximate 1000 year sedimentation life, actually it would take 1400 years to completely fill at this rate but sedimentation will have a definite impact before that time.

The lake has already accumulated sediment for 15 years and lost 1 per cent of its original volume to sediment.

If the sediment is accumulating in the dead storage region of the reservoir, it will have no serious impact on the reservoir for a long time but if a delta is forming at the upstream end of the lake it will be reducing the live storage capacity and causing flooding problems upstream of the reservoir due to backwater.

Cross section data for selected ranges on Lake Diefenbaker have been collected since 1964.[14] Although complete analysis of this data would and has provided a number of thesis topics, a brief summary of some of the results will be useful here. By 1972[13] a clear trend was apparent. The bulk of the deposition is occurring in the upstream end of the lake but not at the extreme west end.

In order to understand this, it is useful to note the normal operating cycle of the reservoir. During the winter, the lake is drawn down 7 to 10 m and it fills each summer. The bulk of the inflowing water and sediment hits the reservoir when it is filling, not when it is full. The sediments, are therefore, deepest near and slightly upstream of the minimum operating level rather than accumulating at the extreme upstream end of the reservoir as would be the case if the lake was full all year. There is some deposition in the extreme west end during the late summer when the lake is near FSL but since this reach becomes river again the following spring, these deposits tend to be reactivated and moved downstream into the reservoir. This process will tend to push the bulk of the sediments into the dead or inactive section of the reservoir for a long period of its early life so that

the live storage will be unaffected until these processes fill a large portion of this dead storage volume.

Since 1972, the sediment data collection program at Lake Diefenbaker has been changed. Before 1972, simple cross sections of the lake were surveyed at selected and carefully marked locations. Since 1972, 600 m wide sections of the reservoir have been surveyed adjacent to the original cross sections. The volume of data collected under the new system exploded so that simple analytic procedures were not possible and although the data were collected regularly, little analysis has been completed due to data processing costs.

All the data on reservoir sedimentation should be processed and analyzed up to the current time. An efficient data collection program that will monitor future sedimentation at a minimum cost should be designed, based on the data collected to date.

D. DOWNSTREAM RIVER SEDIMENT LOAD

As mentioned in the previous section, Lake Diefenbaker completely removes sediment from the water of the South Saskatchewan River. The water at the outlet is clear.

The sediment that was historically in transit down the river had a wide range of particle sizes and was in a constant state of deposition and resuspension as the river meanders shifted. The widely varying flows contributed to the continually changing river pattern.

The lake greatly reduces the flow variations resulting in a more uniform rate of flow and also cuts off the upstream source of sediment material. This clear flowing water has sediment carrying capacity that is unused and it tends to scour sediment material if suitable material is available.

The first material scoured is the fine particles immediately downstream of the dam. As the fine material is removed, the larger particles form a pavement that armours the river channel. With the magnitude and frequency of large floods greatly reduced by reservoir storage, the potential for moving the large sands and gravels is reduced and the rate of scour which may have been high initially slows and approaches a stable condition asympotically.

In order to monitor this change, the Saskatchewan and Canada Departments of the Environment established monumented cross sections[15] from Gardiner Dam to Saskatoon. These cross sections were surveyed in 1964 and 1965 and have been surveyed again at intervals since to measure the changes in the river form. River bed samples at these cross sections are analysed for particle size.

Analysing data from 1966 to 1972, Rasid[16] found that the average bed of the river in the 30 km from Gardiner Dam to Outlook had degraded 0.034 m per year and the thalweg or deepest point on the river had degraded 0.15 m per year. Downstream of Outlook the change has not been as rapid. Also, the main river channel was found to be becoming narrower. The third change that was showing up by 1972 was a shift in bed material size from fine grained toward coarser material.

Northwest Hydraulic Consultants Ltd.[17] completed a detailed evaluation of the sediment erosion occurring downstream of Lake Diefenbaker. They found that the riverbed downstream of Gardiner Dam has dropped 2 metres. They predicted that the will drop a further 2.2 metres by the year 2000 and that ultimate degradation could reach 7.0 m. Most of the erosion is occurring in the upstream 8 km of river in the early years. The erosion will extend further downstream eventually, but its impacts further from the dam will be very slow to materialize. The erosion is greatest in periods of high flow, particularly periods of heavy spill.

With the riverbed slowly degrading, the main impact is on the dam itself. The hydraulic structures were designed for the tailwater conditions at the time of construction. The lower riverbed results in lower tailwater and changed hydraulic performance. For example, the hydroelectric turbines have more net head as a result of the lower tailwater. Since the turbines were not designed to withstand too much lowering of the tailwater, there is a limit to the amount of increase that can be tolerated and remedial efforts to limit the drop in tailwater at the power station by armouring the outlet channel with rock to control this change have been undertaken. Similarly, the spillway hydraulics may have to be adjusted to assure its performance according to its design.

Since this change is expected to occur for an indefinite future and since it is most active immediately downstream of the dam, a program of regular monitoring with emphasis on the area near the dam should be

maintained. If this erosion reaches proportions such that structures are threatened, remedial work such as artificial introduction of coarse material may be necessary to stabilize the river.

Chapter V

DOWNSTREAM FLOW REGIME

A. GENERAL

Lake Diefenbaker is a water management project which is used to supply water for various consumptive uses and to generate electrical energy. In order to use the water, the flow regime is changed. The consumptive uses reduce the total flow and flow regulation through reservoir storage changes the flow pattern. This chapter defines the changes that have occurred.

B. INSTANTANEOUS FLOW RATES

In nature, the flow of a large river, like the South Saskatchewan, does not vary sharply from hour to hour. The long distance from the source of the water and river channel storage has attenuated the flows before they reach the Saskatchewan portion of the river.

Gardiner Dam, with its artificially controlled releases, has changed this. In order to efficiently meet energy demands, which vary sharply, the releases through the power station commonly vary from zero to the full plant capacity of 420 m^3/s within a 24-hour period. The variations depend on the available water supply and the power demands on the system. In winter when the reservoir storage is being drawn down to meet peak demands, the power station is usually base loaded which means the hourly fluctuations are not as extreme. Similarly, if inflows are high in the summer and large quantities of water must be released, the outflow rate is fairly constant. It is in normal or dry summers when inflows are low and the daily mean outflow

is a fraction of the plant capacity that the widest instantaneous outflow fluctuations occur.

As an example, if conditions were such that mean daily release of 200 m^3/s were available for power generation, a rough daily flow pattern would be as shown in Table 3.

TABLE 3

TYPICAL HOURLY FLOW VARIATIONS FOR

MEAN DAILY RELEASE OF 200 m^3/s

Time	Average Release
0000 hr. to 0600 hr.	0 m^3/s
0600 hr. to 0800 hr.	200 m^3/s
0800 hr. to 1400 hr.	400 m^3/s
1400 hr. to 2400 hr.	200 m^3/s

Prior to the project, the flow of the river was never zero and although rapid changes in flow occurred from day to day, the hourly extremes are now much greater.

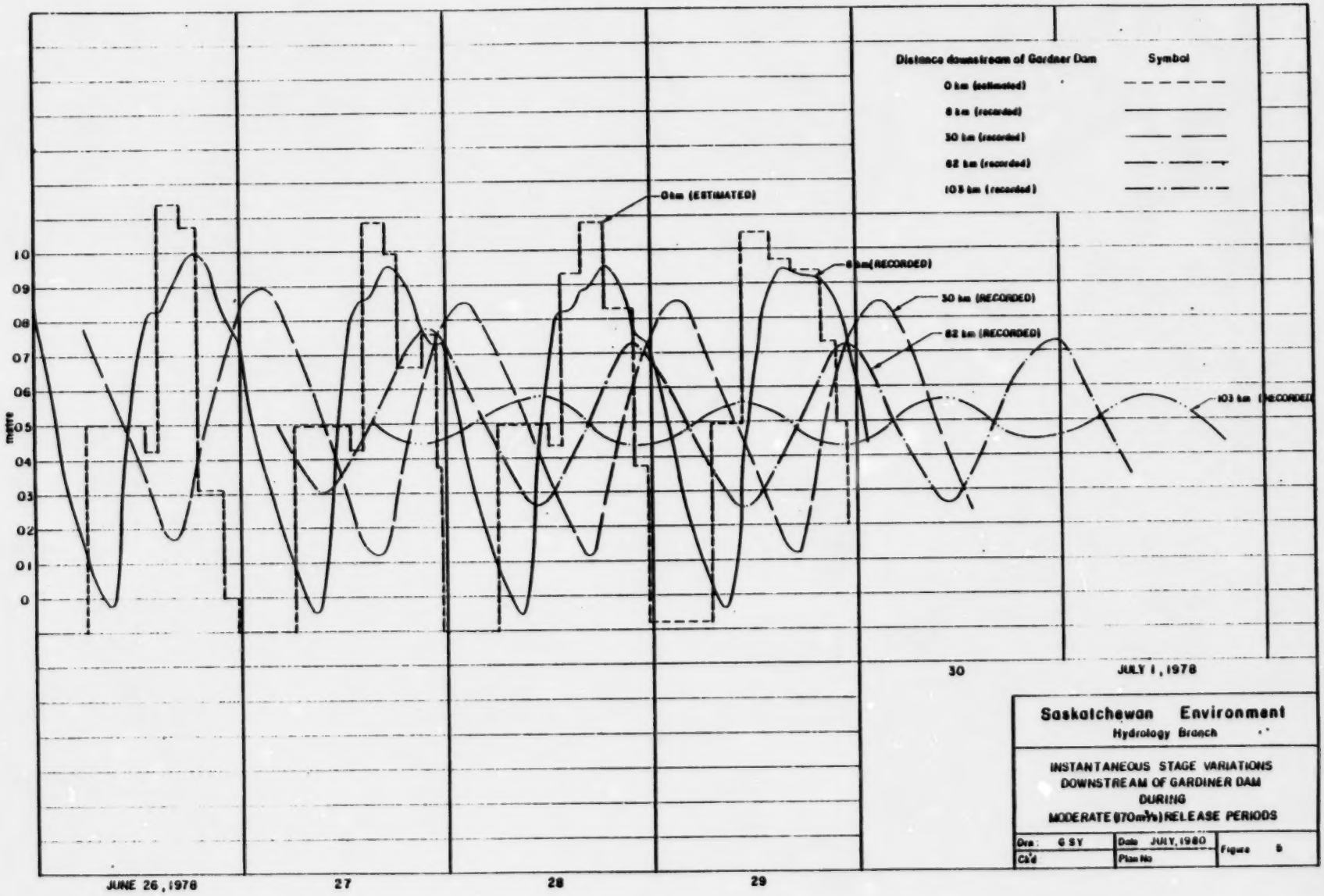
The river channel storage attenuates the flows so that within a few kilometres downstream of the project, the rapid changes are much less extreme. Eight kilometres downstream, Water Survey of Canada operates a water level recorder; at Outlook, 30 kilometres downstream and at Pike Lake, 82 kilometres downstream, the Hydrology Branch of Saskatchewan Environment operates water level recorders and at Saskatoon, 103 km downstream, Water Survey of Canada operates a water

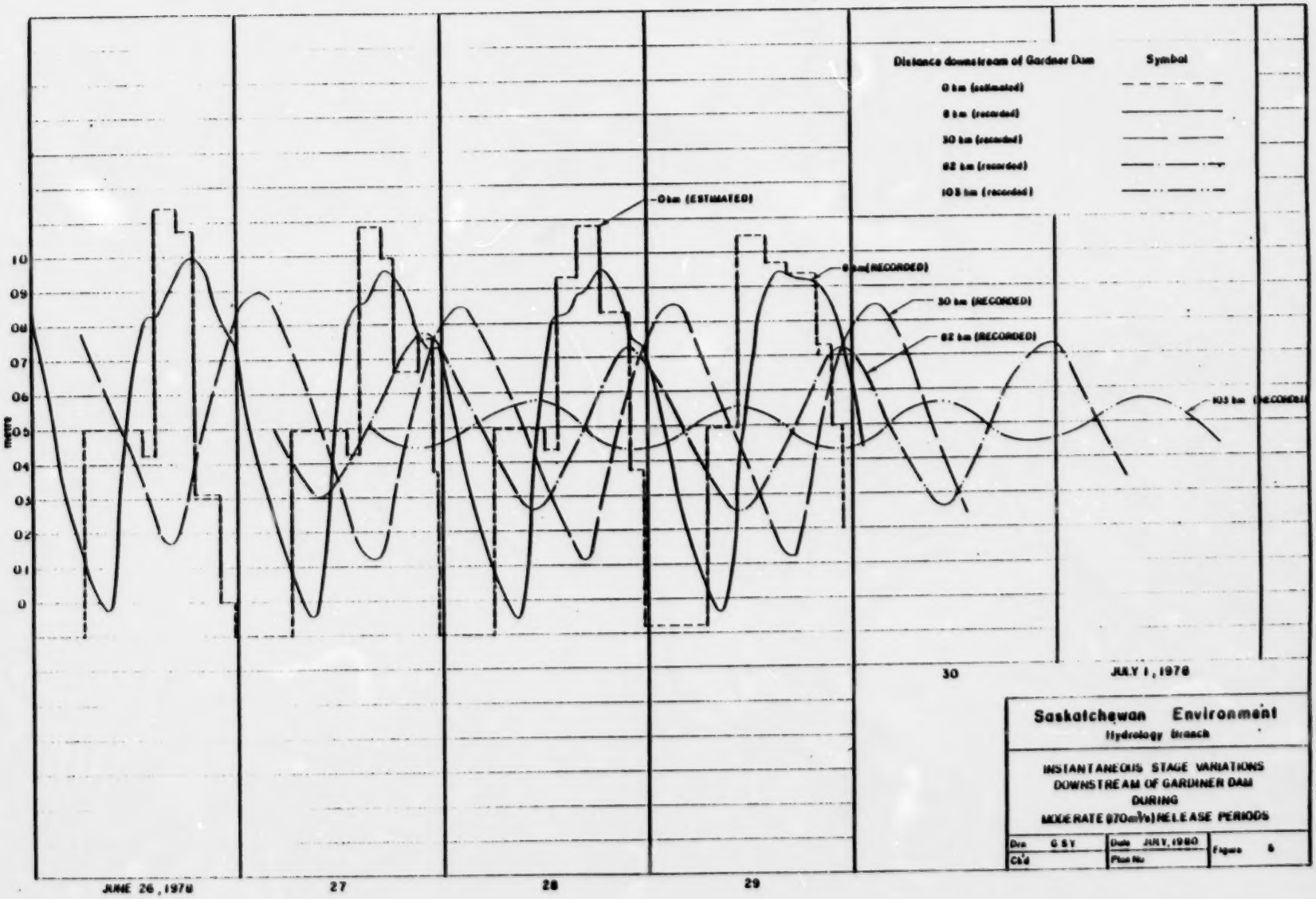
level recorder. Figures 4 and 5 show typical attenuation patterns during summer releases of about 43 m^3/s and 170 m^3/s. These figures reproduce the recorded water levels which reflect the flow pattern.

Figure 4 shows the water level fluctuations resulting from releases during the period from May 3 to 6, 1978 when the daily mean flow was near the lowest limit that is permitted by government policy, 43 m^3/s. Although the instantaneous release pattern is not available, an estimated pattern that could have occurred is shown as a dashed line. Since the power station is operated by remote control, most changes in the outflow rate are instantaneous. The square pattern estimated is realistic.

The water levels shown for 8 km, 30 km, 82 km, and 103 km downstream are copied directly from the water level recorder charts.

The water level 8 km downstream shows a very irregular pattern in response to the sharply changing releases at Gardiner Dam. The stage at this location never stabilizes. Even when the power station is releasing zero flow for about 6 hours, the stage continues to fall which indicates that some outflow from this 8 km reach of river is continuing. The falling stage indicates that the volume of water in storage in the channel is decreasing so outflow is occurring. In spite of sharply changing outflows all the changes in stage 8 km downstream are smoothly curved due to channel attenuation. The stage is varying over a range of nearly one metre which is quite an extreme variation for a regular 24-hour rise and fall on a large river.


Distance downstream of Gardner Dam
Symbol
0 km (estimated)
8 km (recorded)
30 km (recorded)
82 km (recorded)
103 km (recorded)
0km (ESTIMATED)
8km(RECORDED)
30 km (RECORDED)
82 km (RECORDED)
103 km (RECORDED)
metre
10
09
08
07
06
05
04
03
02
01
0
JUNE 26, 1978
27
28
29
30
JULY 1, 1978
Saskatchewan Environment
Hydrology Branch
INSTANTANEOUS STAGE VARIATIONS
DOWNSTREAM OF GARDINER DAM
DURING
MODERATE (170m³/s) RELEASE PERIODS
Drn: G SY
Date JULY, 1980
Ck'd
Plan No
Figure 5


Distance downstream of Gardiner Dam
Symbol
0 km (estimated)
8 km (recorded)
30 km (recorded)
82 km (recorded)
103 km (recorded)
0km (ESTIMATED)
8km(RECORDED)
30 km (RECORDED)
82 km (RECORDED)
103 km (RECORDED)
metres
10
09
08
07
06
05
04
03
02
01
0
JUNE 26, 1978
27
28
29
30
JULY 1, 1978
Saskatchewan Environment
Hydrology Branch
INSTANTANEOUS STAGE VARIATIONS
DOWNSTREAM OF GARDINER DAM
DURING
MODERATE (70m³/s) RELEASE PERIODS
Drn G S Y
Date JULY, 1980
Ckd
Plan No
Figure 6

At the next station, 30 km downstream of the dam, the river storage impact has damped out the minor hourly variations and transformed the stage hydrograph to a smooth nearly sinusoidal wave pattern with a 24-hour cycle. The amplitude of the full cycle is still nearly 1 metre.

At the station 82 km downstream of the dam, the wave pattern is very smooth and the amplitude is down to less than one-third of a metre.

By the time the water leaves Saskatoon, 103 km downstream, the amplitude is down to a few centimetres.

The stage versus discharge curve is not always of constant shape so these comparisons are not necessarily a direct indication of the attentuation of the instantaneous fluctuations in flow but in general the river geometry is similar enough that the stage is usable for comparison. The one exception is at Saskatoon where a concrete weir forms the downstream control and the change in stage is only about one-half as great for similar flow changes. Even if the amplitude were doubled to compensate, it is a small fraction of the upstream values.

There is one more water level recorder operated by Water Survey of Canada on the South Saskatchewan River at St. Louis, 236 km downstream of the dam. Water level variations at this location were not plotted on Figure 4 because no discernible variation would be identified at this scale but careful measurements have shown that a small diurnal variation of about 1 cm carries even this far downstream.

Figure 5 shows the water level fluctuations resulting from releases during the period from June 26 to June 29, 1978 when the daily mean flow was about 170 m^3/s which is about half the hydroelectric station capacity. As mentioned regarding Figure 4, the data on the instantaneous release pattern is not available but an approximate pattern is estimated.

At this daily mean flow the amplitude of instantaneous flow changes is near its maximum since the power station releases vary from zero to near full plant capacity. The stage 8 km downstream of Gardiner Dam cycles a full metre. With distance downstream, the cycling reduces and approaches a smoooth sinusoidal shape due to the damping impact of channel storage. At 30 km the amplitude is about 0.75 m, at 82 km it is about 0.5 km and at 103 km it is down to .15 m. It should be noted that the station at 103 km downstream of Gardiner dam is at the Saskatoon weir where variations in flow produce about one-half the stage variations that would occur in a natural channel. At St. Louis, 236 km downstream of the dam, the variations are not plotted but are still discernible although the amplitude is down to less than 0.02 m.

As daily mean flows are increased and approach the generating plant capacity, the instantaneous fluctuations reduce and the stage variations are less extreme.

In critical periods such as the fall freeze-up of the river when such wide stage fluctuations could precipitate ice jams and cause floods, the variations in releases are limited to a narrow range. In the

winter when power demands are highest, the generating station is operated at near plant capacity so variations are small.

The extremes shown on Figures 4 and 5 are typical of the summer season when the outflows are usually low in order to fill the storage reservoir and when there is no ice to create flooding hazard.

C. DAILY FLOW RATES

During the period from 1912 when flow records were first collected on the South Saskatchewan River at Saskatoon until the mid 1960s, when Lake Diefenbaker began influencing the flow, the rate of flow varied widely.

The lowest flow occurred December 12, 1936, when the flow was 14.2 m^3/s. The highest flow occurred June 15, 1953, when 3936 m^3/s of water was measured. The median low flow was 31 m^3/s and the median annual maximum was 1275 m^3/s.

Since the project has been in operation, the flow range has been significantly narrower. An operating policy specifies a minimum release rate of 43 m^3/s. The release has never been less than this since the fall of 1968. The period of record since is too short to establish an accurate median minimum release but an approximation would be about 70 m^3/s.

The maximum flow, since the project was in operation, was 1900 m^3/s on June 26, 1975. This release occurred when a flood inflow was passed

out of the lake through the hydro turbines and the spillway. The flow that would have passed down river would have been large, 2760 m^3/s, if the dam were not in operation but it would not have been as large as the 3936 m^3/s mentioned above so a direct comparison is not applicable. If the 1953 flood occurred after the project was in operation, the flood peak would be substantially reduced, probably to about 2500 m^3/s by reservoir storage. The median of the maximum annual releases has been slightly below the hydro turbine capacity of the power station or 400 m^3/s and this is expected to be the long-term median maximum daily release rate.

In summary, the daily mean flow extremes which ranged from 14.2 m^3/s to 3936 m^3/s prior to the project now range from 43 m^3/s to about 2500 m^3/s; and the normal or median range which was from 31 m^3/s to 1275 m^3/s is now from 70 m^3/s to 400 m^3/s. The minimum flows are 2 to 3 times as high now and the maximum one-third to two-thirds of the preproject conditions. The median maximum daily flow historically exceeded the minimum daily flow by a factor of 41. The ratio is now 6.

The new higher minimum flow makes the river a much better and more convenient water supply source and a more reliable assimilator of sewage effluent and other pollutants.

The lower flood peaks make the river and its floodplain less hazardous, reduce bridge costs and future spillway costs when dams are built downstream.

In general, reducing the extremes of flow improves the river's compatibility with most forms of human usage. This change is most noticeable on the South Saskatchewan River from Gardiner Dam to the confluence with the North Saskatchewan River. Since the North Saskatchewan is an approximately equal sized river, the impact of Lake Diefenbaker is substantially diluted at the confluence of the two rivers.

D. MONTHLY AND SEASONAL FLOW RATES

Because of its large storage capacity, Lake Diefenbaker is operated on an annual planning basis. The lake is filled in the summer when inflows are highest and emptied in winter when water has its greatest value for hydroelectric generation. The seasonal flow pattern of the South Saskatchewan River has been vastly altered. In order to determine the magnitude of the changes, a detailed evaluation of monthly inflows, outflows, water uses and storage was completed and is attached as Appendix A to this report.

The inflows to the reservoir were calculated as the measured flow of the South Saskatchewan River and its major tributaries plus an estimate of the minor inflow from local tributaries. The results are detailed in Tables A.2 to A.11 in Appendix A and summarized in Table 4 of this report. Since the estimated local inflows represent 0 to 3.5 per cent of the total inflow, the quoted data can be considered to be nearly as reliable as recorded flow data which is usually considered to be within a few per cent of the true values.

TABLE 4

INFLOW TO LAKE DIEFENBAKER

$m^3 \times 10^6$

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1969	271	229	400	1929	1433	1753	2653	630	348	340	265	197	10448
1970	185	194	313	880	1032	2188	1101	420	232	310	296	217	7368
1971	203	280	295	1712	1361	2195	827	495	250	270	289	159	8336
1972	164	158	767	821	1553	2692	1585	917	561	489	373	191	10271
1973	242	245	476	718	913	1461	864	398	305	243	205	260	6321
1974	209	239	308	1506	1996	2591	1308	642	413	309	248	206	9975
1975	205	162	256	745	1547	2535	1426	479	403	400	263	281	8702
1976	334	323	580	647	1045	848	780	1188	544	341	223	185	7038
1977	206	247	287	300	357	487	251	338	296	274	167	157	3369
1978	145	175	470	753	1145	1805	1051	617	762	584	288	298	8093
Mean	216	225	415	1001	1238	1855	1184	612	411	356	262	215	7992
Max.	334	323	767	1929	1996	2692	2653	1188	762	584	373	298	10448
Min.	145	153	256	300	357	487	251	338	232	243	167	157	3369
Std. Dev.	52	51	153	499	423	706	607	249	158	102	54	47	2031
Std. Dev. /Mean	.24	.23	.37	.50	.34	.38	.51	.41	.38	.29	.21	.22	.25

Precipitation and evaporation on the lake surface were calculated from meteorologic data and water temperature measurements of the Atmospheric Environment Service of Environment Canada. Reservoir storage changes were determined from water level measurements and the volume of Lake Diefenbaker measured by topographic surveys prior to construction of the reservoir. Monthly precipitation, evaporation and changes in storage are listed in Tables A.13 to A.22 in Appendix A.

Outflow from Lake Diefenbaker to the South Sakatchewan River is not measured until it reaches Saskatoon. In order to estimate the outflow from Gardiner Dam, it was necessary to deduct an estimated local inflow component. Table A.25 to A.34 in Appendix A lists the monthly outflows from Lake Diefenbaker. Table 5 summarizes the monthly releases to the South Saskatchewan River.

Water also flows out of Lake Diefenbaker to the Qu'Appelle River, to the East Side Diversion canal and to minor irrigation projects around the lake.

All the major components of the monthly water balance of Lake Diefenbaker are listed in Tables A.35 to A.44 in Appendix A. For convenience in the evaluation of the seasonal flow changes, the data summarized in Tables 4 and 5 can be compared.

Table 5, Inflow to Lake Diefenbaker, lists the volume of water entering Lake Diefenbaker each month in the decade from 1969 to 1978. If the lake had not been in operation, this would also have been the

TABLE 5

SOUTH SASKATCHEWAN RIVER BELOW GARDINER DAM

$m^3 \times 10^6$

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1969	993	939	955	738	832	792	2023	618	477	544	701	915	10527
1970	993	788	525	243	334	492	514	491	384	599	576	870	6809
1971	912	919	852	634	631	912	377	218	220	350	636	907	7568
1972	861	771	958	800	538	792	1194	871	625	576	665	856	9507
1973	1011	905	608	281	244	371	361	310	453	490	574	878	6486
1974	876	710	941	826	877	1245	785	583	505	406	543	726	9023
1975	851	765	613	389	541	1464	1060	400	301	566	702	813	8465
1976	956	799	704	410	209	181	205	1576	560	616	549	877	6642
1977	950	640	337	192	134	136	132	132	123	141	414	579	3910
1978	588	423	488	363	149	629	446	356	613	614	587	636	5892
Mean	899	765	698	488	449	701	710	456	426	490	595	806	7483
Max.	993	939	958	826	877	1464	2023	871	625	616	702	915	10527
Min.	588	423	337	192	134	136	132	132	123	141	414	579	3910
Std. Dev.	117	145	209	227	261	411	549	206	159	144	82	112	1848
Std. Dev. /Mean	.13	.19	.30	.46	.58	.59	.77	.45	.37	.19	.14	.14	.25

flow of the South Saskatchewan River below Gardiner Dam. The mean, the maximum, the minimum, the standard deviation and the ratio of the standard deviation to the mean of the ten flows for each calendar month are also listed along with the annual values. Table 5, South Saskatchewan River below Gardiner Dam has a similar listing. The difference between Table 4 and Table 5 is the impact of Lake Diefenbaker.

All 120 monthly values were analysed. The mean monthly inflow was 665 x 10^6 m^3. The mean monthly outflow was 623 x 10^6 m^3. A reduction of 42 x 10^6 m^3 or 6 per cent of the inflow. The total flow was reduced 6 per cent by the project. This will be discussed further in the next section of this chapter.

The standard deviation of the 120 inflows is 615 x 10^6 m^3. The standard deviation of the 120 outflows is 299 x 10^6 m^3. This confirms the observation reached from the daily flow range. That is, the flow pattern is much less variable as a result of Lake Diefenbaker. In nature, the standard deviation almost equalled the average flow whereas the standard deviation of the outflows is now less than half of the average.

The difference between inflow and outflow for the 120 months of study are listed in Table 6 and the difference, as a per cent of the inflow, is listed in Table 7. The means and standard deviations of these differences are also listed.

TABLE 6

IMPACT OF LAKE DIEFENBAKER ON SOUTH SASK. MONTHLY FLOWS

$m^3 \times 10^6$

Year	Jan.	Feb	.Mar.	Apr.	May	June	July	Aug.	Sept.	Oct	Nov.	Dec.	Total
1969	722	710	555	-1191	-601	-961	-630	-12	129	204	436	718	79
1970	808	594	212	-637	-698	-1696	-587	71	152	289	280	653	-559
1971	709	639	557	-1078	-730	-1283	-450	-277	-30	80	347	748	-768
1972	697	613	191	-21	-1015	-1900	-391	-46	64	87	292	665	-764
1973	769	660	132	-437	-669	-1090	-503	-79	148	247	369	618	165
1974	667	471	663	-680	-1119	-1346	-523	-59	92	97	295	520	-952
1975	646	603	357	-356	-1006	-1071	-366	-79	-102	166	439	532	-237
1976	622	476	124	-237	-836	-667	-575	-612	16	275	326	692	-396
1977	744	393	50	-108	-223	-353	-119	-206	-173	-133	247	422	541
1978	443	248	18	-390	-996	-1176	-605	-261	-149	30	199	338	-2201
Mean	683	540	283	-513	-789	-1154	-474	-156	15	134	333	591	-509
Std. Dev.	96	135	215	367	252	428	146	185	117	123	62	127	720

TABLE 7

IMPACT OF LAKE DIEFENBAKER AS A PER CENT OF THE MONTHLY INFLOWS

$m^3 \times 10^6$

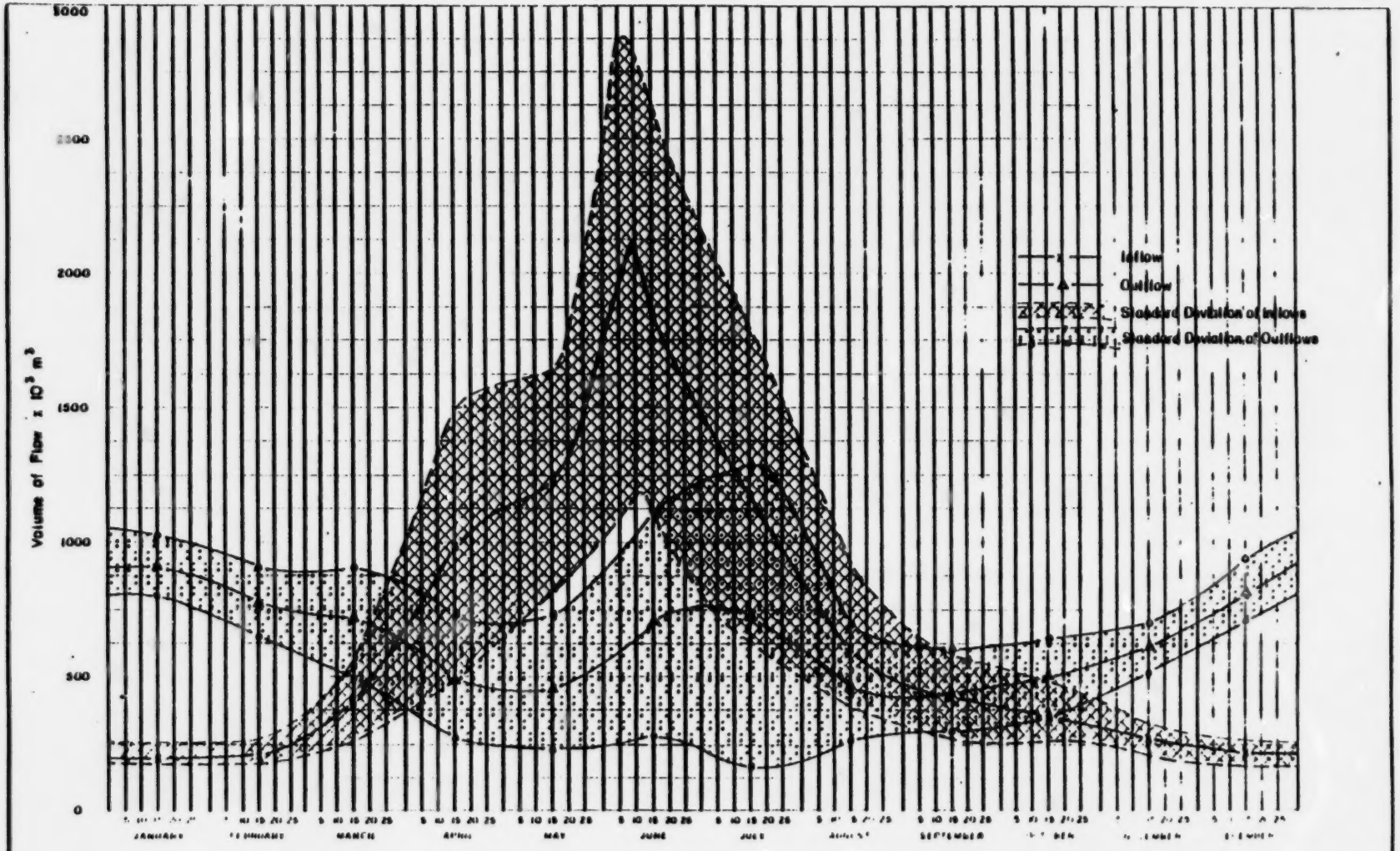
Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct	Nov.	Dec.	Total
1969	366	410	239	38	58	45	76	98	137	160	264	464	101
1970	537	406	168	28	32	22	47	117	196	193	195	401	92
1971	449	328	289	37	46	42	46	44	88	130	220	570	91
1972	525	488	125	97	35	29	75	95	111	118	178	448	93
1973	418	367	128	39	27	25	42	80	149	202	280	338	103
1974	419	297	306	55	44	48	60	91	122	131	219	352	90
1975	415	472	239	52	35	56	74	84	75	142	267	289	97
1976	286	247	121	63	20	21	26	48	103	181	246	474	94
1977	461	259	117	64	38	28	53	39	42	51	248	369	116
1978	406	242	104	48	13	35	42	58	80	105	204	313	73
Mean	428	352	184	52	35	35	54	75	110	141	232	402	95
Std. Dev.	69	86	73	19	12	11	16	25	41	43	32	82	10

The impact is very consistent from year to year. The flow from April to August is reduced and from October to March it is increased. September is the only month where the impact is positive in some months and negative in some months.

In May and June, when the bulk of the reservoir storage occurs, the impact of the lake is a very large reduction in the downstream flows. On the average, only about one-third of the inflow is released in this period. In July through September, the proportion rises until releases from storage result in augmented outflows. This augmentation peaks in January when maximum hydroelectric generation results in flows more than four times their unregulated values. Through February and March the rate of release from storage reduces. Figure 6 provides a graphical presentation of the difference between the mean monthly inflows and outflow. The standard deviation range is also shown since the overlap of these ranges shows the times of year when the impact of the lake is least and the lack of overlap in winter and early summer indicates that in these periods the flows are greatly affected by the lake.

In summary, Lake Diefenbaker has resulted in much less seasonal variation in the flow of the South Saskatchewan River. Winter flows are much higher and early summer flows much lower as a result of the project.

Downstream of the confluence with the North Saskatchewan River, the percentage impact due to Lake Diefenbaker is substantially reduced. It is interesting to note that the North Saskatchewan River is also



Saskatchewan Environment Hydrology Branch		MONTHLY INFLOW VERSUS OUTFLOW	Figure
Drn GSY	Date JULY , 1980		6
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regulated for hydroelectric generation in Alberta and although the regulation is not as large as that due to Lake Diefenbaker, a somewhat similar pattern of impact exists. The result is very large winter flows and reduced summer flows on the Saskatchewan River compared to historic values. Major regulation at Cedar Lake and Lake Winnipeg in Manitoba render any impact of Lake Diefenbaker on seasonal flow patterns insignificant on the Nelson River.

E. ANNUAL FLOWS

Lake Diefenbaker was built to permit the use of water for economic activities. The use of water for hydroelectric generation is not consumptive and does not deplete the flow of the river. Diversions to the Qu'Appelle River, to irrigation projects and to industrial users do deplete the flow. As mentioned earlier, the total flow of the South Saskatchewan River is depleted about 6 per cent by the project.

Since the North Saskatchewan is a similar sized river, the net impact of Lake Diefenbaker downstream of the confluence of the North and South Saskatchewan Rivers is diluted to about 3 per cent which is an insignificant impact on discharge . As downstream tributaries add flow, the impact is further diluted so that at the Manitoba border and downstream the average annual flow is not noticeably different due to Lake Diefenbaker.

It is worthwhile to note that although Lake Diefenbaker changes the monthly and seasonal distribution of flows significantly, its storage

does not affect annual flows to a large extent. The ratio of the standard deviation to average annual flow is 0.25 for both the annual inflows and outflows which means the lake is not carrying water over from wet years to augment the flow in dry years.

Chapter VI

QU'APPELLE RIVER FLOW REGIME

A. GENERAL

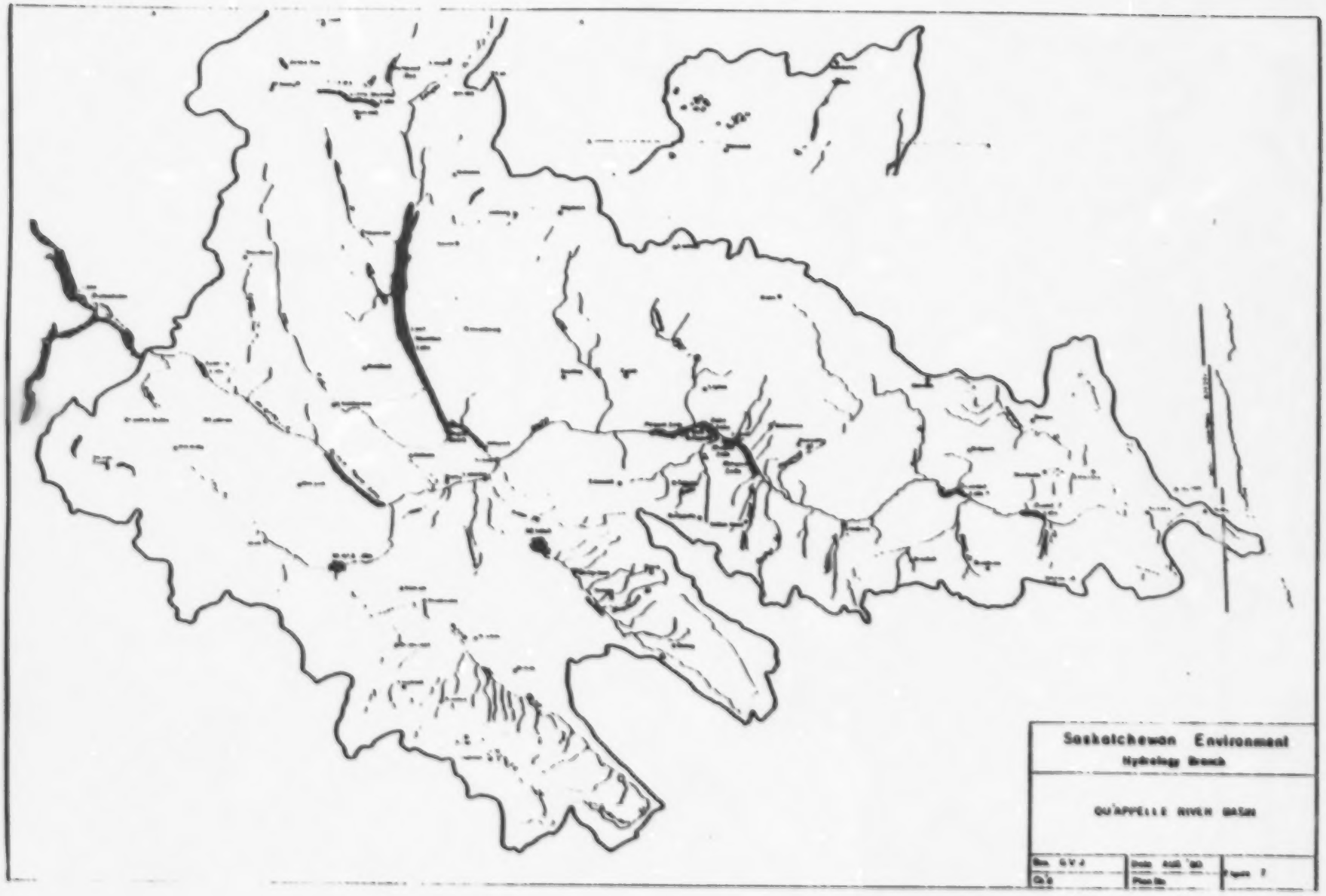
As mentioned in Chapter II, a large glacial spillway river once used the South Saskatchewan and Qu'Appelle River Valleys to convey water eastward across the prairies. When Lake Diefenbaker was built, the resultant interconnected valleys created an easy point of diversion from the South Saskatchewan River to the heavily used Qu'Appelle River System. The purpose of this chapter is to identify how much impact on flow that interconnection has had on the Qu'Appelle River System.

B. QU'APPELLE RIVER DESCRIPTION

Figure 7 shows that the Qu'Appelle River extends from Lake Diefenbaker to the Assiniboine River, a short distance east of the Saskatchewan-Manitoba border. The river travels 780 km in 375 km of valley distance. The Qu'Appelle River has 7 lakes along its channel and it is connected to two additional lakes. All these lakes are natural lakes which have artificial controls added, creating reservoirs for water control and water use.

Eyebrow Lake is a waterfowl production project in the Qu'Appelle Valley adjacent to the Qu'Appelle River. This project relies on Lake Diefenbaker water to offset summer evaporation losses.

Buffalo Pound Lake is an instream reservoir that serves recreation use as well as being the source of water for Regina and Moose Jaw, potash mining at Belle Plaine and downstream agriculture water needs.


Saskatchewan Environment
Hydrology Branch
QU'APPELLE RIVER BASIN

The natural inflow to Buffalo Pound Lake is inadequate to meet these needs and water from Lake Diefenbaker is used to meet the deficit in local supply. It is interesting to note that even before Lake Diefenbaker was in operation water was pumped from the South Saskatchewan River to Buffalo Pound Lake to meet these needs.

Last Mountain Lake is a large off stream natural storage which receives water from the Qu'Appelle River during floods and returns it to the river during low flow periods. Artificial control works have been built to partially control the inflow and outflow at Last Mountain Lake. There is extensive recreational development on Last Mountain Lake that results in the need for stable lake levels. The lake area of about 20,000 hectares has a greater average annual evaporation potential then the total inflow of the small creeks that flow into the lake so the lake relies on the Qu'Appelle River for water to maintain its level. In nature, the lake would vary over a 5 metre range of levels. In order to stabilize the lake, flood waters must be wasted and in dry periods water must be diverted to the lake. In a series of dry years, Last Mountain Lake could become a significant demand on Lake Diefenbaker if its level is maintained from this source.

Pasqua, Echo, Mission and Katepwa Lakes are in stream storage reservoirs grouped near the Town of Fort Qu'Appelle. These lakes are also heavily developed for recreation and stable water levels are desirable. In dry years, the natural flow is not always adequate to offset evaporation so Lake Diefenbaker water could be used to maintain these lake levels.

Round Lake and Crooked Lake are located at the downstream end of the Qu'Appelle River and generally receive an adequate natural water supply.

Water use in the Qu'Appelle Valley for irrigation in the summer is now possible by using Lake Diefenbaker as a water source. This demand on Lake Diefenbaker could become significant.

C. IMPACT ON QU'APPELLE RIVER FLOWS

The release of water from Lake Diefenbaker to the Qu'Appelle River is monitored at the station named Elbow Diversion Canal at Drop Structure. At first glance, one might conclude that this is a direct measure of the impact of Lake Diefenbaker on the Qu'Appelle River system. In fact, this would be an upper limit to the impact rather than being a direct measure of the impact. Water is not diverted to the Qu'Appelle River unless there is a demand to be met. Water which is released from Lake Diefenbaker then used in the upper Qu'Appelle River does not add to the flow further down the system. Some of the water diverted to the Qu'Appelle is used consumptively in industry, agriculture and lake evaporation. Some is not consumed. Examples of non-consumptive use would include the 80 per cent of municipal water which is returned to the river as sewage effluent or the water that is provided for water quality control or aesthetics through dilution and maintenance of a flowing stream.

An alternative argument that could be proposed would suggest that even if Lake Diefenbaker water were not available, the same uses would be

developed based on local Qu'Appelle River basin water. In some cases, this is correct. In these cases, the availability of Lake Diefenbaker water is reducing the use of Qu'Appelle River basin water and is thus indirectly increasing the flow of the Qu'Appelle River.

This whole question of whether users of Qu'Appelle River water are actually using Lake Diefenbaker water is a very difficult administrative question that is under serious consideration by Saskatchewan's Water Managers.

For this report, only the gross diversion to the Qu'Appelle River is analyzed on the basis that this is the upper limit of diversion impacts.

Appendix C lists the monthly and annual diversion of water to the Qu'Appelle River and provides a comparison to the total flow at three downstream locations:

1. Qu'Appelle River above Buffalo Pound Lake.
2. Qu'Appelle River below Craven.
3. Qu'Appelle River at Tantallon (or near Welby).

Table 8 summarizes the annual diversion.

Above Buffalo Pound Lake the diversion is the majority of the total flow. In some years, the diversion has exceeded the flow measured

TABLE 8

ANNUAL DIVERSION OF LAKE DIEFENBAKER WATER TO THE QU'APPELLE RIVER

Year	Diversion $m^3 \times 10^6$	Qu'Appelle River Flow					
		Above Buffalo Pound Lake		Craven		Tantallon (Or near Welby)	
		Volume $m^3 \times 10^6$	%Diversion	Volume $m^3 \times 10^6$	%Diversion	Volume $m^3 \times 10^6$	%Diversion
1969	34	89	38	211	16	302	11
1970	28	57	49	294	10	398	7
1971	75	40	188	205	37	301	25
1972	72	75	96	97	74	164	44
1973	87	84	104	78	112	84	104
1974	20	94	21	653	3	770	3
1975	51	39	131	414	12	713	7
1976	23	43	53	434	5	840	3
1977	24	66	36	49	49	91	26
1978	48	51	94	34	141	80	60
Average	46	64	72	247	19	373	12

above Buffalo Pound Lake. This indicates that some of the diversion was for consumptive uses in the upstream valley and did not impact on the downstream flows confirming the comments regarding the diversion being the upper limit of potential impact.

In general, the diversion of water from Lake Diefenbaker has greatly changed the flow pattern of the Qu'Appelle River above Buffalo Pound Lake. Appendix C indicates that there is flow in most months instead of the April and May period that nature would have provided. The average values in Table 8 indicate that the total flow in this reach is nearly doubled by diversion of water.

Further downstream on the Qu'Appelle River at Craven the natural flows have been increased by tributary inflow and the impact of diverted water is diluted. Table 8 shows that in occasional low flow years such as 1973, 1977 and 1978, the diversion flows are a major contribution to the total flow. In high runoff years, the significance of the diversion flows becomes negligible. The average diversion is 19 per cent of the total flow. The diversion ranges from 3 per cent in the flood year 1974, to 112 per cent in the drought of 1973.

At the downstream end of the Qu'Appelle River, the average percentage has been diluted to 12 per cent and the diversion flow is a smaller portion of the total flow in most years than it was at the upstream locations, ranging from 3 per cent to 104 per cent.

In summary, the diversion of water from Lake Diefenbaker to the Qu'Appelle has its largest impact at the upstream end of the Qu'Appelle where it represents 100 per cent of the flow. Downstream the average impact reduces to 64 per cent above Buffalo Pound Lake, 19 per cent at Craven and 12 per cent at the east end of the Qu'Appelle River. The impact is greatest in dry years when the demands for water are high and the natural flow is low. The impact is insignificant in wet years when demands for water are low and the natural flows are high.

The average diversion of 46 x 10^6 m^3 per year is about one-half of the estimates from the preconstruction studies quoted in Chapter III. This is because the past decade has been relatively wet* so local Qu'Appelle River water has met the demands. Also, some of the expected demands have been slower to develop than was expected.

The pattern of diversion identified in the preconstruction studies indicated that releases would mostly occur in summer. This reflected expected major irrigation demands and ice problems that would prevent winter diversions. The recorded diversions have been spread throughout the year because operating experience has demonstrated that ice is not a limitation if rapid changes in flow are avoided and the major summer demands have not materialized.

* During the decade of the study, the flow of the Qu'Appelle River at Craven averaged 250 x 10^6 m^3 per year. After deducting the 46 x 10^6 m^3 of Lake Diefenbaker release this quantity would be 204 x 10^6 m^3 per year. During the previous 58 year period the average flow was 49 x 10^6 m^3 per year.

Chapter VII

GROUND WATER

A. GENERAL

Lake Diefenbaker raised the water level in 230 km of the South Saskatchewan River Valley by an average of about 25 m. Since the valley was the discharge point for the regional ground water in this area of Saskatchewan, this rise in water level caused adjustments in the ground water regime. Since ground water flows cannot be measured by current meters or other direct measuring devices, indirect measures are necessary. Ground water impacts of Lake Diefenbaker were considered through two indirect approaches. A surface water balance for the lake was calculated to see if a significant net inflow to or outflow from the reservoir could be identified; and data on subsurface pressure gradients were reviewed to determine if an impact has occurred.

B. SURFACE WATER BALANCE

Appendix A contains a detailed month by month listing of all the inflows to, outflows from and changes in storage at Lake Diefenbaker from 1969 to 1978. Tales A-35 to A-44 in Appendix A summarized the results of this water balance. The residuals in Tables A-35 to A-44 represent the amount by which the surface water balance failed to balance. If all measurements were precise, this residual would have to be the ground water flow. Table 9 summarizes these residuals for the 120 months under study and for the annual values. An average and standard deviation for each month is also provided.

TABLE 9

ANALYSIS OF RESIDUALS FROM SURFACE WATER BALANCE

($m^3 \times 10^6$)

Month	Year										Average	Standard Deviation
	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978		
January	55	10	-5	64	44	-40	-33	-139	-30	2	-72	56
February	52	3	-19	64	128	-27	-10	-62	31	0	23	49
March	37	61	20	-46	46	4	-4	-60	120	46	22	50
April	-20	-73	-79	161	84	-28	35	132	49	162	42	67
May	-135	-153	-165	-225	-116	-157	-37	-128	-31	-155	-130	55
June	-235	-247	-153	-155	-126	-231	-216	-10	-22	-101	-150	82
July	-8	4	55	0	47	126	108	-9	17	48	39	45
August	62	13	-5	76	0	-2	23	-120	-36	-53	-4	54
September	124	12	2	7	38	79	-16	-1	-16	3	23	43
October	-60	-11	1	14	156	3	-6	51	-17	-48	8	57
November	64	-56	-69	-28	-30	3	39	-64	-110	-43	-29	50
December	22	11	25	-93	102	-37	67	-4	-23	-55	2	54
TOTAL	-42	-426	-394	-163	373	-319	-50	-414	-68	-194	-170	231

Van Everdingen[2] demonstrated that ground water levels in the Riverhurst area are substantially above the Lake Diefenbaker water surface level so that although the rate of ground water discharge to the South Saskatchewan River Valley should be reduced by the presence of the reservoir, it should continue to be a discharge. The average discharge shown in Table 9 is -170×10^6 m^3 per year, which indicates a loss of water. A review of ground water well records[18] at areas around Lake Diefenbaker indicates that the condition of positive gradient toward the lake is not unique to the Riverhurst area. Therefore, the overall loss of water to ground water must be rejected and other explanations for the residuals identified.

The simplest explanation is that it is a net result of measurement error. This 170×10^6 m^3 would only require a 2 per cent error in the flow record. Since this residual resulted from a balance of inflow and outflow it would only represent a 1 per cent error in each measurement. Hydrometric data collection agencies would accept that as a good standard of accuracy. Since two components of the water balance, evaporation and precipitation were arrived at by indirect calculations, a greater error could be assigned to these and the flow measurement portion of the balance could be considered better than 1 per cent accurate.

It can be concluded that the annual ground water inflow to Lake Diefenbaker is too small compared to the total inflow to be calculated by a water balance study. Considering Van Everdingen's[8] 1968,

estimate of 3×10^{-6} m^3/s per m of valley, the ground water flow to 236 km of valley would be $22 \times 10^6 m^3$ per year which is indeed too small to expect to show-up in this water balance.

The monthly residuals are less easily accommodated. An average residual of 130×10^6 m^3 in May on an average flow of 1238×10^6 m^3 would require a consistent error of 10 per cent in the flow records. In the case of June, the average residual of 150×10^6 m^3 requires a consistent error of 8 per cent. These are too large to be explained as measurement errors. It can be concluded that there is some physical cause for these apparently large losses of water. In the remaining 10 months, there is an apparent tendency to gain water that is small and is not consistent from month to month.

The significant loss during May and June, when the reservoir is usually filling combined with the net gain of water in the remaining portion of the year, indicates that the storage factor used in the water balance may be too small. The reservoir itself could be slightly larger than the area curve on Figure 3 indicates or there could be bank storage.

The erosion discussed in Chapter VIII would create an increase in the area, particularly at the upper levels of the shoreline, of up to 5 per cent. The storage calculations could be in error by up to 5 per cent which would partially explain the residual in Table 8.

Bank storage, that is, the movement of water into the soils of the rservoir bank while the lake fills and the return of this water as the lake drains would also create a greater storage capacity than the impervious reservoir assumed for the water balance in Appendix A. These two factors combined could explain the 8 to 10 per cent average residuals in May and June.

Measurements of the area could be taken to confirm adjustments to the area curve by the use of air photo mapping techniques. The bank storage component cannot be conveniently measured. In order to improve future water balance calculations for Lake Diefenbaker, the area and storage curves could be adjusted to provide for about 200 x 10^6 m^3 of added storage capacity in the portion of the reservoir that usually fills in May and June.

The surface water balance does not provide a quantitative indication of the impact of Lake Diefenbaker on ground water except that it provides some evidence of significant bank storage.

C. GROUND WATER GRADIENTS

As mentioned in Chapter III, Van Everdingen installed a series of piezometers to monitor the changes in pressure gradient of the ground water that resulted from the Lake Diefenbaker project. The piezometers were operated until 1970.[2] That is, they monitored conditions while the lake filled from 1964 to 1968 and the first two years of operation of the project. Observations have continued but analytical reporting ended in 1970.

Van Everdingen's report[2] on the results of this monitoring concluded that, as expected, piezometric pressures adjacent to the reservoir did increase in response to the presence of the higher water level in the valley. The increased pressures were due to the hydraulic connection between the surface water and the ground water in the bedrock aquifers. The water level of the reservoir determines the outlet pressure of the ground water system in the region. The upstream pressurs must adjust in order to regain the gradient necessary to move the inflowing water to an outlet. The further from the lake that the pressures were measured, the lower the change and the slower it occurred.

Some of the piezometers near the reservoir responded immediately to the reservoir filling while the more distant and deeper piezometers had not all stabilized by 1970 when the program was terminated. The pressure increases that occurred in the bedrock aquifers were greater than the predicted values. In the overburden, the increases were smaller than predicted. Although the rate of discharge to the valley from ground water has been slowed by the increased discharge pressure, a positive discharge is still indicated. Piezometer pressures at some locations are above ground level so that ground water has become more readily available at wells.

If the piezometers that were installed in 1964 could be analysed now, a decade after the last detailed analysis, some useful results for determining the longer term changes might be obtained.

D. SUMMARY

Ground water discharge to Lake Diefenbaker is too small relative to the total flows and the accuracy of measurement of these flows to permit determination through a water balance calculation.
The water balance calculation indicates a slightly larger storage capacity may exist at Lake Diefenbaker partially due to temporary ground water or bank storage. The reservoir itself may be slightly larger than original measurements indicate.

Ground water levels and pressure gradients adjacent to Lake Diefenbaker adjusted rapidly to the new higher ground water discharge pressure but further from the reservoir the adjustment was slower and is likely continuing.

Chapter VIII

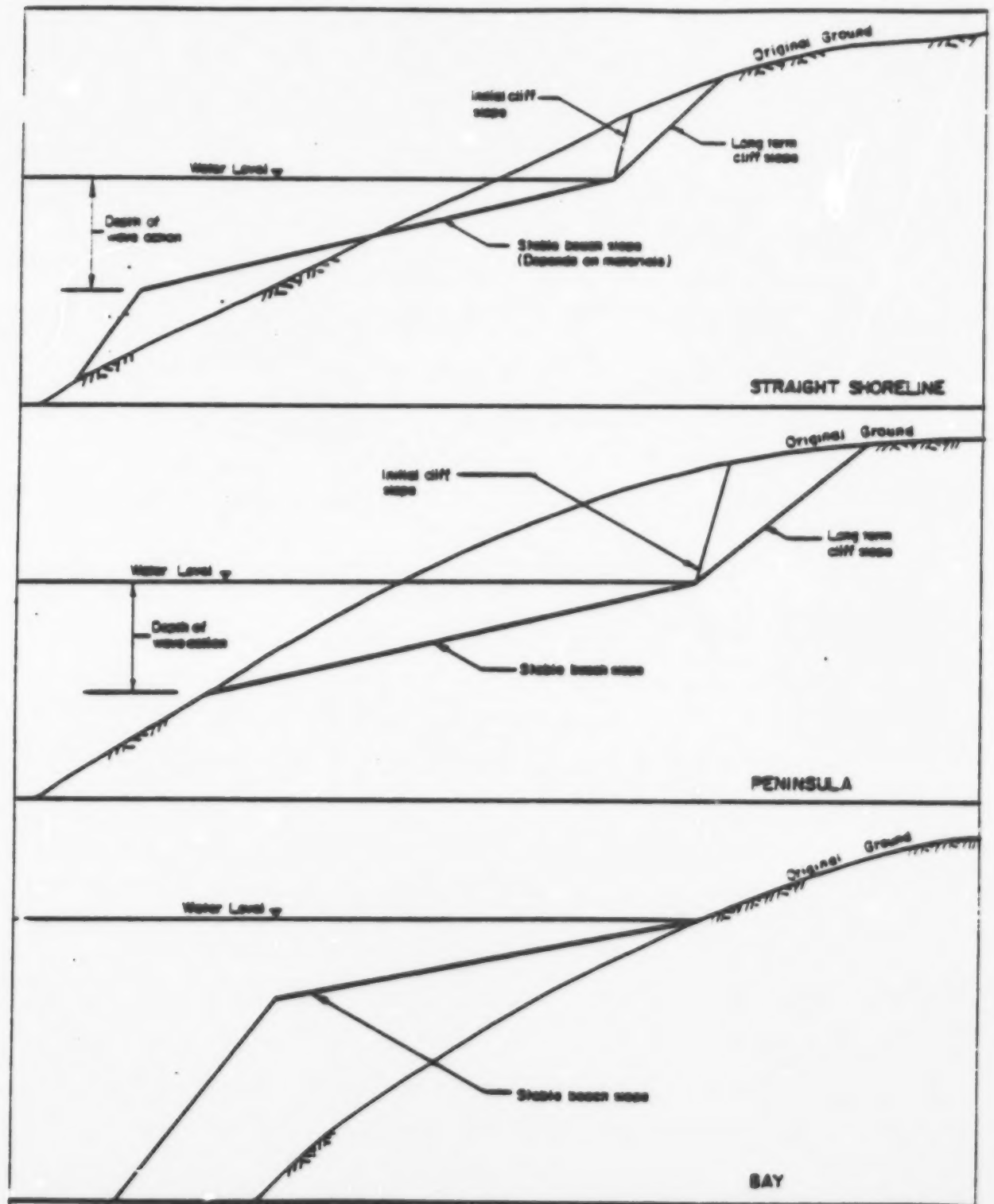
SHORELINE EROSION

A. NATURE OF EROSION

The side slopes of the South Saskatchewan River Valley were at slopes that were stable under the dry conditions that prevailed prior to filling of Lake Diefenbaker. Actually, many areas were not even totally stable prior to the lake but the very slow creep failures that were occurring were only significant with respect to long-term considerations. The imposition of the new lake environment created a new inbalance that nature must accommodate. Depending on the terraine and type of materials, the valley slope at the new shoreline varied widely. An average slope of about 1:15 existed. The valley soils varied from the clay like shales to tills which can be very fine grained or coarse. Stable beach slopes depend on the type of material. Mollard[1] suggested beach slopes as flat as 1:30 would be required in many areas.

Figure 8 is a schematic diagram of the extent of erosion for a constant lake level and three shoreline configurations: a straight shore, a peninsula and a bay. This diagram shows how the wave action will excavate bank material and deposit it in the lake until the beach slope adjusts to a more stable condition. This diagram is based on general literature plus personal experience of the author.

On a straight shoreline, the excavated material will build up in the deep water. Lateral movement of material will occur but an equilibrium of movement along the shore will generate a net fill below the water and excavation at the shoreline.



Saskatchewan Environment Hydrology Branch		SHORELINE EROSION FOR CONSTANT RESERVOIR LEVEL	Figure
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On a peninsula, the lateral movement of excavated material will prevent the build-up of fill in the offshore area at the peninsula and the flatter beach slope will be developed totally through excavation.

In a bay, the lateral movement of material from adjacent headlands will provide the flatter beaches almost totally through filling. In some deep bays, the filling will close the mouth of the bay with a sand-bar.

B. LAKE DIEFENBAKER

Figure 8 provides for a constant lake level. The stable beach only has to cover the depth of wave action which will be between 1 and 2 metres depending on exposure and fetch. Lake Diefenbaker acts as a reservoir and the level varies up to 10 metres. A stable beach must develop over this full range of levels. This will take much longer and will result in more severe erosion than that pictured on Figure 8. The annual rise of Lake Diefenbaker through the summer acts as a large plane repeatedly leveling and smoothing the shoreline. In order to obtain 1:30 beach slopes over a 10 metre elevation range, the beaches will ultimately be 300 metres wide.[9]

Air photos, taken in 1967 when the lake was initially filling, revealed a very irregular shore. Straight or smoothly curving segments were non-existent. By 1972 when the lake was again photographed, broad beaches were evident, the lakeshore was smoothed with many peninsulas eliminated and bays filled with soil and steep cliffs as high as 10 m had formed. Aerial and ground reconnaisance indicates that the process is still very active.

The continued existence of near vertical cliffs indicates that the beach formation continues to undercut the cliffs each year. The cliffs have not had time to begin to reach a stable condition. Once the beach begins to stabilize, it will cease or reduce the rate of undercutting the cliffs and the natural upland erosion processes of rain, wind and gravity slumping will reduce the steepness of cliffs as shown on Figure 8.

Development of shoreline recreation has generally allowed for this erosion. However, at some locations the erosion has exceeded expectations and threatened structures. Careful control of future shoreland development will be needed for the long-term future to avoid further problems.

In order to trace this impact in the future, vertical air photos of the reservoir should be obtained at intervals of a few years.

Chapter IX

MISCELLANEOUS PHYSICAL IMPACTS

A. METEOROLOGIC IMPACT

A large new reservoir can have meteorologic impacts through two processes; heat storage and evaporation.

A 60 m deep water body stores more solar energy than the surrounding prairie during the warm sunny summer. Clear water has a lower albedo than soil so more solar energy is absorbed and less is reflected. The energy received is mixed in the whole depth of the reservoir so it is not reradiated from a temporarily hot surface through long wave radiation as is the case for the prairie soils. Energy is stored in the full 60 m depth of water as heat whereas soil only stores heat in the top metre or two.

The conversion of 43,000 hectares of arid prairie to a water surface greatly enhances the evaporation potential of the reservoir area. The evaporation of over 300×10^6 m^3 of water per year from the reservoir surface is a change in the local environment.

When considered on the scale of the millions of hectares of the prairie region, the impact of this enhanced heat storage and added water vapour is so diluted that it is not significant. However, locally there are some small effects.

Buckler[19] studied meteorologic data for two locations near Lake Diefenbaker: Elbow and Birsay and found that the temperature range of

daily maximum to minimum at Elbow is reduced about 3°C in the fall and about 1°C in spring due to the heat storage in Lake Diefenbaker. The Elbow weather station is slightly under 100 m from the lake. At Birsay, 4 km from the lake no noticeable effect was evident. The effect on wind and humidity was too small to measure but a few cases of extreme hoar frost on cold days in the fall within 500 m of the lake are documented. Although no measurements demonstrate it, the regional smoothing of the topography resulted from filling this large valley with water must have had some local impact.

Lake Diefenbaker's impact on climate is limited to a small region within one kilometre of the shoreline.

B. RIVER ICE

The South Saskatchewan River below Gardiner Dam carries winter flows that are augmented by water released from storage in Lake Diefenbaker. These flows are 4 to 5 times the unaugmented winter flows. Ice conditions on the river have changed as a result.

The water released in winter from Gardiner Dam comes from the bottom of Lake Diefenbaker where its temperature will be the maximum density temperature of water or about 4°C. The air temperature above the water is well below freezing. The water loses heat to the air and freezes but this takes some time during which the water travels downstream. The result is an open water reach downstream of Gardiner Dam throughout the winter extending 8 to 30 km depending on the air temperature.

The large flow delays freeze-up of the river which used to occurin mid November to mid or even late December. The freeze-up is accompanied by ice jamming and hanging frazil ice dams which cause flooding problems along the river in early winter that never occurred before the Lake Diefenbaker project.

On the other hand, spring break up ice jams have been eliminated by storage of early spring flows in the lake and controlled declining flows instead of irregular rises and drops.

C. RETENTION TIME

Lake Diefenbaker has a volume of 9.36×10^9 m^3. The mean annual flow of the South Saskatchewan River is 8.00×10^9. On the average it takes 1.17 years for a water molecule to travel through the lake. Prior to construction of this project water moved through this reach of river in about two days or 0.005 years.

Chapter X

SUMMARY OF RESULTS

A. SEDIMENT REGIME

1. Reservoir Sedimentation

Lake Diefenbaker is 100 per cent efficient in trapping the sediment load of the South Saskatchewan River. This sediment is accumulating in the west end of the reservoir at a rate that will fill the lake in about 1400 years if no change in the upstream river basin occurs. It will be several hundred years before sedimentation has any significant impact on the reservoir. The main delta is forming at the west end of the reservoir when the reservoir is at its minimum operating level.

Measurements of sedimentation have been fairly concentrated in the early years of project operation. These measurements should continue but in recognition of the time scale for this impact to become significant, the measurement program need not continue at such a concentrated rate. The data collected to date should be fully analysed and a future program carefully planned based on the results of this analysis.

2. Downstream River Channel

Water leaving Lake Diefenbaker at Gardiner Dam has no sediment load and it is, therefore, scouring the river sands causing erosion and degradation of the river channel. The fine material is eroding first and as a result, the remaining sand is coarser and less erodable. The South Saskatchewan River channel has

little very coarse material so armouring is limited and erosion of the channel is expected to continue indefinitely.

Data collected indicates that the river channel has already degraded about 2 metres and can be expected to degrade an additional 2.2 metres by the year 2000. Ultimate degradation of 7 metres could occur.

The rate of erosion varies with the flow and significant impact occurs in flood years when water is spilled at high rates from Lake Diefenbaker.

The maximum rates of degradation are occurring near Gardiner Dam with no measurable impact 30 km downstream. As the degradation continues, the distance of impact downstream will increase.

This degradation could impact on Gardiner Dam and river structures downstream in time. Measurement of this degradation should be continued with special emphasis on the segment of river near Gardiner Dam where the impact is greatest. Through the use of mathematical modeling techniques, the erosion process can be reasonably estimated from fewer measurement than would be the case without the modeling so the frequency of measurement should be reduced with emphasis placed on years when high flows occur.

Studies of the effect on hydraulic structures at the dam and along the river should be undertaken to determine the magnitude and timing of impacts on their performance. If necessary,

remedial actions should be planned. Relatively simple actions such as artificially introduced armouring or rock weirs might stabilize the erosion at critical locations.

B. DOWNSTREAM FLOW REGIME

1. Instantaneous Flows

Efficient use of the limited water flow for hydroelectric generation requires extreme variations of the outflow from Lake Diefenbaker from hour to hour. In periods of low mean daily releases in the summer, the resultant slugged releases typically generate flow cycles that cause the water level in the first few kilometres below Gardiner Dam to rise and fall through a range of over one metre.

The amplitude of the cycling decreases downstream as the storage impact of the channel attenuates the flows. After 30 km of distance, the amplitude is about three quarters of a metre. At 82 km amplitude is a third to a half metre. A distance of 236 km downstream the cycling is very smoothed but is still easily measured.

The instantaneous flow changes are greatest in periods when the mean daily flows are about one-half of the hydro power station capacity. At greater flows more of the daily cycle has high flows and at mean daily flows equal to or near the plant capacity no cycling occurs. At very low flows, the cycling at the plant

is extreme but the impact downstream is less because the river channel storage quickly attenuates the smaller volumes released in the brief high flow periods.

2. Daily Flow Variations

The range of daily mean flows has been substantially reduced by Lake Diefenbaker.

Flow extremes which would range from 14 to 2926 m^3/s without Lake Diefenbaker now range from 43 to 2500 m^3/s. The annual median daily mean flow extremes are reduced from a minimum of 31 and a maximum of 1275 m^3/s to a range of 70 to 400 m^3/s.

Minimum flows are 2 to 3 times as high and maximums one to two-thirds of preproject conditions. The annual median maximum daily flow historically exceeded the annual median minimum by a factor of 41. The ratio is now 6.

The resultant reduced range of water level fluctuation generally improves the usefulness of the river for usual human uses. Floods are lower and water supplies and effluent dilution are more reliable.

3. Monthly and Seasonal Flows

The average monthly flow of the South Saskatchewan River is reduced 6 per cent by the Lake Diefenbaker project. The average monthly flow volume is reduced from 665 x 10^6 m^3 to 623 x 10^6 m^3.

The standard deviation of the 120 monthly flows studied would be 615 x 10^6 m^3, nearly equal to the average flow, without Lake Diefenbaker. The lake reduced it to 299 x 10^6 m^3 or less than half the average flow. The flow pattern is much less variable as a result of project.

The impact on seasonal flow pattern is very consistent from year to year. Releases from storage from November to March always augment the flow and storage of water from April to August always reduce the flow. In September the flow is usually augmented but only by a small amount and not in every year. Winter flows are typically quadrupled and summer flows one-third to one-half as a result of the project. Figure 6 on page 51 conveniently demonstrates the changed seasonal flow pattern.

4. Annual Flows

Although Lake Diefenbaker has been very significant in changing seasonal flow patterns, it has not significantly altered the annual flows of the South Saskatchewan River. The evaporation loss and water uses reduce the flows by 6 per cent. The average flow is 94 per cent of that which would occur without the project.

The standard deviation of the annual flows is 25 per cent of the mean annual flows with or without Lake Diefenbaker. This indicates that the storage capacity of the lake is not being used to carry water from wet years to dry years.

C. QU'APPELLE RIVER FLOWS

Water from Lake Diefenbaker is released to the Qu'Appelle River. Some of this water is utilized consumptively by projects and some augments the flow of the Qu'Appelle River. For this study the quantity consumed was ignored and the total release was assumed to augment the flow. As a result, the impact identified is an upper limit.

An average of 46 x 10^6 m^3 of water per year is diverted from the South Saskatchewan River system to the Qu'Appelle River system at Lake Diefenbaker. This varies from a low of 20 x 10^6 m^3 in the wet year, 1974, to a maximum of 87 x 10^6 x m^3 in the dry year, 1973.

In comparison to the total flow, this average diversion varies from 100 per cent at the Qu'Appelle Valley Dam to 72 per cent upstream of Buffalo Pound Lake, 19 per cent east of Craven and 12 per cent at the downstream end of the Qu'Appelle River.

In wet years when the diversion is small and the total flow is high, the diversion per cent becomes an insignificant contribution to Qu'Appelle River flows. In dry years the diversion occasionally provides almost all the flow of the Qu'Appelle River.

Diversion of water from Lake Diefenbaker to the Qu'Appelle has greatly reduced the variation in flows of the Qu'Appelle River.

Because the study period has been relatively wet in the Qu'Appelle River basin, the average diversion has been about half as large as was expected from planning studies.

D. GROUND WATER

Regional ground water pressures around Lake Diefenbaker are substantially above the lake level and ground water discharge to the reservoir must exist.

The quantity of ground water discharge is too small to be detected from a surface water balance. Even small errors in surface water flow measurement will mask the ground water flow.

The increased water level in the South Saskatchewan River Valley resulting from Lake Diefenbaker has raised the discharge pressure for the regional ground water system resulting in less gradient toward the lake, raised pressures and water tables in the area and less discharge to the lake. The water not reaching the lake can temporarily go into storage in rising ground water levels but discharge adjustments to other outlets must also occur.

With the wide range of reservoir levels bank storage will augment the storage capacity of the lake. The surface water balance calculations confirm a greater storage capacity than the original reservoir surveys. This could be partially the result of shoreline erosion but is probably also the result of bank storage.

Some effort to follow up on measurements of this impact that were initiated in 1964 might produce interesting results.

E. SHORELINE EROSION

A new lake in a relatively steep sided valley, like the South Saskatchewan River Valley, will make vast changes to the landscape in its early years of existence until stable beaches form and the irregularities of the shoreline are smoothed by wave action. At Lake Diefenbaker the wide range of operating levels requires a very broad beach. The many side coulees and valley wall hills provide a very irregular shoreline for the lake which must smooth with time. Shoreline erosion has been very rapid in the early years of operation of this project and it has a long way to go before it can be expected to stabilize.

In order to protect against damages to economic activities, stringent control over land use will be necessary for a long time into the future.

Monitoring of the shoreline changes through aerial photography should be carried out every few years so future impacts can be projected to aid rational planning of shoreline facilities.

F. MISCELLANEOUS IMPACTS

1. Meteorology

Lake Diefenbaker affects the weather within a narrow distance, 1 kilometre or less, of its shoreline. Temperatures are stabilized and moisture conditions may be enhanced. Beyond this narrow band, the lake does not significantly change the prairie climate.

2. River Ice

The high winter flows result in abnormal open water all winter immediately downstream of the dam, delayed fall freeze-up of the river and greater freeze-up season ice jamming than occurred prior to the project. Spring ice jam problems have been eliminated.

3. Retention Time

On the average it takes slightly more than one year for a molecule of water to pass through Lake Diefenbaker.

Chapter XI

CONCLUSIONS

Lake Diefenbaker was created to stabilize the water supply to an arid area of southern Saskatchewan and to generate electrical energy. Beside accomplishing these objectives, the project has had a substantial impact on its physical environment as detailed in this report.

Although the project has not greatly changed the total flow of the South Saskatchewan River, it has vastly altered the seasonal pattern of flow. The natural cycle of high summer flows and low winter flows has been largely eliminated and in many years totally reversed.

The sediment discharge of the river is being trapped by the reservoir so that the reservoir is slowly filling with sediment while the clean water leaving the reservoir is scouring the downstream channel. Shoreline erosion is also contributing to sedimentation in the reservoir and is significantly altering the landscape.

Systems such as ground water and the Qu'Appelle River which are attached to the Lake Diefenbaker through hydrologic interconnections have been altered by the reservoir and the reservoir is having local impacts on its own shoreline.

These impacts are generally of a type that will continue for a long time into the future and have already or could in the future reach economic significance. Shoreline erosion limits the type and design of shoreline uses. Sedimentation may change the storage capacity of the reservoir in

the long run. Degradation of the river downstream of the project will require consideration in the design of river structures such as bridges and municipal water intakes. Surface and ground water flow changes alter the water regime and charge access to the water resource. Therefore, surveillance of these impacts through regular monitoring programs will be needed as long as the project exists.

Chapter XII

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APPENDIX A

MONTHLY WATER BALANCE OF

LAKE DIEFENBAKER

A.1 INTRODUCTION

Lake Diefenbaker filled during the period from 1964 to 1968. By the winter of 1968-69, the project was in full operation. For this study it has been assumed that full operation started in January, 1969 and the ten year study period ending in December, 1978 is considered.

This appendix describes the computation of a monthly water balance for Lake Diefenbaker for this ten-year period.

A.2 INFLOW

The majority of the inflow to Lake Diefenbaker comes from the South Saskatchewan River. The flow of the South Saskatchewan River is not gauged between Lake Diefenbaker and its first major upstream tributary, the Red Deer River. Therefore, the flow of the South Saskatchewan River into Lake Diefenbaker must be calculated from the sum of the measured flow of the South Saskatchewan River at Highway 41 (05AK001)[20] and the Red Deer River near Bindloss (05CK004).[20] Both these hydrometric stations are located a short distance west of the Alberta-Saskatchewan border.

Swift Current Creek discharges a small quantity of water directly into Lake Diefenbaker. This creek was gauged near the mouth (05HD037)[20] in 1969 and 1970 and a short distance upstream near Leinan (05HD039)[20] during the remaining years in the study period.

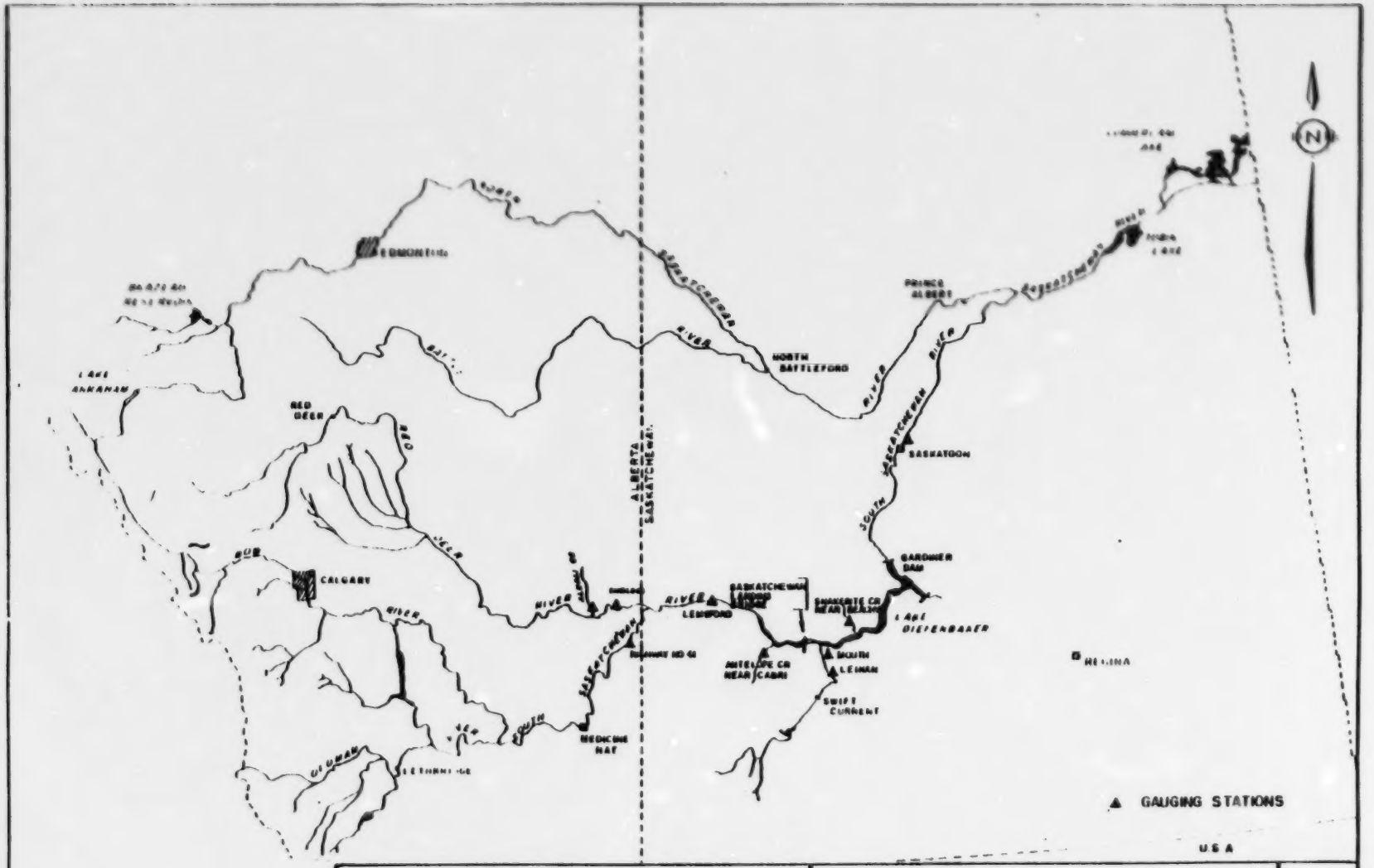
Two other small creeks that discharge into the reservoir have been gauged since 1970: Snakebite Creek near Beechy (05HE001)[20] and Antelope Creek near Cabri (05HC005).[20]

There is a considerable drainage area that is tributary to Lake Diefenbaker that is not gauged but this area is extremely dry and poorly drained so it does not contribute much water. Even though the quantity is small, ignoring it would introduce a systematic error into evaluations, therefore, the local inflow was estimated.

The basis of this estimate was a comparision of the effective or net dry drainage areas as described by Stichling and Blackwell[21] of gauged streams and the ungauged area. This effective drainage area requires a subjective judgement for definition. PFRA[22] completed an evaluation of gross and effective drainage areas in 1978. Since this evaluation was completed using consistent criteria, its results were used for this study. Table A.1 lists the gross and effective drainage areas, tributary to the key points in this evaluation. Figure A.1 shows the location of the points of interest.

In 1969, the only record of the flow of a small creek that was collected in this geographic region was on Alkali Creek near the Mouth (05CK005)[20] which is a tributary to the Red Deer River in Alberta. The effective ungauged area to Lake Diefenbaker was 5848 km^2. Based on the effective drainage area ratio, the ungauged inflow was estimated to be 24.1 times the flow of Alkali Creek.

In 1970, two new gauging stations were added to the network in the Lake Diefenbaker area: Antelope Creek near Cabri and Snakebite Creek near Beechy. Although these only measure runoff from a small portion



Saskatchewan Environment Hydrology Branch		STREAMFLOW GAUGING NETWORK	Figure
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TABLE A.1

INFLOW DRAINAGE AREAS

Location	Drainage Area Km^2	
	Effective	Gross
South Saskatchewan River at Gardiner Dam	86583	135583
South Saskatchewan River at Highway 41	46604	65959
Red Deer River near Bindloss	31489	44662
Swift Current Creek near the Mouth	2642	3911
Swift Current Creek near Leinan	2595	3724
Alkali Creek near the Mouth	242	591
Antelope Creek near Cabri	115	191
Snakebite Creek near Beechy	208	860
South Saskatchewan River near Lemsford	79860	119370
South Saskatchewan River at Saskatchewan Landing	81585	125644

of the local area, they provide a reliable index of local runoff conditions. Using these plus Alkali Creek the local ungauged effective area was divided in three segments:

1. Upstream of Lemsford
2. Lemsford Ferry to Saskatchewan Landing Bridge
3. Saskatchewan Landing Bridge to Gardiner Dam

Local inflow in Area 1 equals 7.3 times the flow of Alkali Creek.

Local ungauged inflow in Area 2 equals 14.0 times the flow of Antelope Creek.

Local ungauged inflow in Area 3 equals 10.3 times the flow of Antelope Creek. In 1971, when the gauging station on Swift Current Creek was moved upstream to near Leinan, the ungauged area increased to 2195 and the ratio to 10.6

Swift Current Creek was moved upstream to near Leinan, the ungauged area increased to 2195 and the ratio to 10.6.

It should also be noted that the Swift Current Creek station was not operated 12 months of the year in 1969 to 1972. Low flows in the winter months were estimated based on recorded values from 1973 to 1978.

Tables A.2 to A.11 show the inflow to Lake Diefenbaker from 1969 to 1978.

TABLE A.2

1969 INFLOW TO LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sask. R. at Hwy. 41	Red Deer R. near Bindloss	Swift Current Creek	Total Gauged Inflow	Alkali Creek	Ungauged Inflow	Total Inflow
January	250	21	0	271	0	0	271
February	210	19	0	229	0	0	229
March	379	20	1	400	0	0	400
April	876	632	54	1562	15	367	1929
May	1147	281	5	1433	0	0	1433
June	1480	271	2	1753	0	0	1753
July	1875	773	5	2653	0	0	2653
August	402	224	4	630	0	0	630
September	205	138	5	348	0	0	348
October	229	107	4	340	0	0	340
November	224	39	2	265	0	0	265
December	164	32	1	197	0	0	197
TOTAL	7441	2557	83	10081	15	367	10448

TABLE A.3

1970 INFLOW TO LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sask. R. at Hwy. 41	Red Deer R. near Bindloss	Swift Current Creek	Antelope Creek	Snakebite Creek	Total Gauged Inflow	Alkali Creek	LOCAL UNGAUGED INFLOW				Total Inflow
								West of Lemsford	Lemsford S.Landing	S.Landing To Dam	Total	
Jan.	168	17	0	0	0	185	0	0	0	0	0	185
Feb.	180	14	0	0	0	194	0	0	0	0	0	194
Mar.	248	32	14	1.2	0	295	.2	1	17	0	18	313
Apr.	359	336	70	0.6	9.2	775	.4	3	8	94	105	880
May	838	186	6	0	0.2	1030	0	0	0	2	2	1032
June	1641	532	9	0	0.5	2183	0	0	0	5	5	2188
July	699	396	6	0	0	1101	0	0	0	0	0	1101
Aug.	259	157	4	0	0	420	0	0	0	0	0	420
Sept.	125	102	5	0	0	232	0	0	0	0	0	232
Oct.	215	89	6	0	0	310	0	0	0	0	0	310
Nov.	255	39	2	0	0	296	0	0	0	0	0	296
Dec.	199	17	1	0	0	217	0	0	0	0	0	217
TOTAL	5186	1917	123	2	10	7238	.6	4	25	101	130	7368

TABLE A.4

1971 INFLOW TO LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sask. R. at Hwy. 41	Red Deer R. near Bindloss	Swift Current Creek	Antelope Creek	Snakebite Creek	Total Gauged Inflow	Alkali Creek	LOCAL UNGAUGED INFLOW				Total Inflow
								West of Lemsford	Lemsford S.Landing	S.Landing To Dam	Total	
Jan.	186	17	0	0	0	203	0	0	0	0	0	203
Feb.	260	20	0	0	0	280	0	0	0	0	0	280
Mar.	253	38	4	0	0	295	0	0	0	0	0	295
Apr.	577	939	62	3.0	5.4	1586	4	27	42	57	126	1712
May	1110	244	7	0	0	1361	0	0	0	0	0	1361
June	1801	386	7	0	.1	2194	0	0	0	1	1	2195
July	588	232	6	0	.1	826	0	0	0	1	1	827
Aug.	331	160	4	0	0	495	0	0	0	0	0	495
Sept.	149	96	5	0	0	250	0	0	0	0	0	250
Oct.	181	83	6	0	0	270	0	0	0	0	0	270
Nov.	254	33	2	0	0	289	0	0	0	0	0	289
Dec.	136	22	1	0	0	159	0	0	0	0	0	159
TOTAL	5826	2270	104	3	5	8208	4	27	42	59	128	8336

TABLE A.5

1972 INFLOW TO LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sask. R. at Hwy. 41	Red Deer R. near Bindloss	Swift Current Creek	Antelope Creek	Snakebite Creek	Total Gauged Inflow	Alkali Creek	LOCAL UNGAUGED INFLOW				Total Inflow
								West of Lemsford	Lemsford S.Landing	S.Landing To Dam	Total	
Jan.	154	10	0	0	0	164	0	0	0	0	0	164
Feb.	147	11	0	0	0	158	0	0	0	0	0	158
Mar.	648	107	9	0	0.2	764	0.1	1	0	2	3	767
Apr.	585	231	5	0	0	821	0	0	0	0	0	821
May	1382	167	4	0	0	1553	0	0	0	0	0	1553
June	2294	396	2	0	0	2692	0	0	0	0	0	2692
July	1135	449	1	0	0	1585	0	0	0	0	0	1585
Aug.	677	239	1	0	0	917	0	0	0	0	0	917
Sept.	408	152	1	0	0	561	0	0	0	0	0	561
Oct.	381	106	2	0	0	489	0	0	0	0	0	489
Nov.	323	48	2	0	0	373	0	0	0	0	0	373
Dec.	178	12	1	0	0	191	0	0	0	0	0	191
TOTAL	8312	1928	28	0	0	10268	0	1	0	2	3	10271

TABLE A.6

1973 INFLOW TO LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sask. R. at Hwy. 41	Red Deer R. near Bindloss	Swift Current Creek	Antelope Creek	Snakebite Creek	Total Gauged Inflow	Alkali Creek	LOCAL UNGAUGED INFLOW				Total Inflow
								West of Lemsford	Lemsford S.Landing	S.Landing To Dam	Total	
Jan.	216	26	0	0	0	242	0	0	0	0	0	242
Feb.	223	22	0	0	0	245	0	0	0	0	0	245
Mar.	384	69	2	0	0.2	455	2.6	19	0	2	21	476
Apr.	322	393	2	0	0	717	0.1	1	0	0	1	718
May	627	285	1	0	0	913	0	0	0	0	0	913
June	1035	424	1	0	0	1460	0.1	1	0	0	1	1461
July	572	292	0	0	0	864	0	0	0	0	0	864
Aug.	197	191	1	0	0	389	0	0	0	0	0	389
Sept.	154	150	1	0	0	305	0	0	0	0	0	305
Oct.	158	84	1	0	0	243	0	0	0	0	0	243
Nov.	165	39	1	0	0	205	0	0	0	0	0	205
Dec.	231	28	1	0	0	260	0	0	0	0	0	260
TOTAL	4284	2003	11	0	0	6298	2	21	0	2	23	6321

TABLE A.7

1974 INFLOW TO LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sask. R. at Hwy. 41	Red Deer R. near Bindloss	Swift Current Creek	Antelope Creek	Snakebite Creek	Total Gauged Inflow	Alkali Creek	LOCAL UNGAUGED INFLOW				Total Inflow
								West of Lemsford	Lemsford S.Landing	S.Landing To Dam	Total	
Jan.	186	23	0	0	0	209	0	0	0	0	0	209
Feb.	218	21	0	0	0	239	0	0	0	0	0	239
Mar.	281	27	0	0	4.7	308	0	0	0	0	0	308
Apr.	577	752	25	4.4	1.1	1363	4.3	31	62	50	143	1506
May	1283	665	5	1.9	0	1956	0.1	1	27	12	40	1996
June	2146	440	2	.2	0	2588	0	0	3	0	3	2591
July	1013	294	1	0	0	1308	0	0	0	0	0	1308
Aug.	465	175	2	0	0	642	0	0	0	0	0	642
Sept.	285	126	2	0	0	413	0	0	0	0	0	413
Oct.	196	109	4	0	0	309	0	0	0	0	0	309
Nov.	204	42	2	0	0	248	0	0	0	0	0	248
Dec.	178	27	1	0	0	206	0	0	0	0	0	206
TOTAL	7032	2701	44	6	6	9789	4	32	92	62	186	9975

TABLE A.8

1975 INFLOW TO LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sask. R. at Hwy. 41	Red Deer R. near Bindloss	Swift Current Creek	Antelope Creek	Snakebite Creek	Total Gauged Inflow	Alkali Creek	LOCAL UNGAUGED INFLOW				Total Inflow
								West of Lemsford	Lemsford S.Landing	S.Landing To Dam	Total	
Jan.	186	18	1	0	0	205	0	0	0	0	0	205
Feb.	147	15	0	0	0	162	0	0	0	0	0	162
Mar.	237	17	1	0	0.1	255	0	0	0	1	1	256
Apr.	407	191	14	2.2	8.3	622	0.6	4	31	88	123	745
May	1230	297	11	0.2	0.4	1539	0.1	1	3	4	8	1547
June	2368	163	4	0	0	2535	0	0	0	0	0	2535
July	1246	178	2	0	0	1426	0	0	0	0	0	1426
Aug.	334	141	4	0	0	479	0	0	0	0	0	479
Sept.	313	86	4	0	0	403	0	0	0	0	0	403
Oct.	324	72	4	0	0	400	0	0	0	0	0	400
Nov.	229	32	2	0	0	263	0	0	0	0	0	263
Dec.	265	15	1	0	0	281	0	0	0	0	0	281
TOTAL	7286	1225	48	2	9	8570	1	5	34	93	132	8702

TABLE A.9

1976 INFLOW TO LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sask. R. at Hwy. 41	Red Deer R. near Bindloss	Swift Current Creek	Antelope Creek	Snakebite Creek	Total Gauged Inflow	Alkali Creek	LOCAL UNGAUGED INFLOW				Total Inflow
								West of Lemsford	Lemsford S.Landing	S.Landing To Dam	Total	
Jan.	317	16	1	0	0	334	0	0	0	0	0	334
Feb.	303	19	1	0	0	323	0	0	0	0	0	323
Mar.	361	78	31	0	5.2	478	0.1	0	46	55	102	580
Apr.	406	176	10	3.3	3.5	596	0.2	1	13	37	51	647
May	947	93	4	0.9	0.1	1044	0	1	0	1	1	1045
June	671	164	6	0	0.6	842	0	0	0	6	6	845
July	602	173	4	0	0.1	779	0	0	0	1	1	780
Aug.	920	263	5	0	0	1188	0	0	0	0	0	1188
Sept.	416	123	5	0	0	544	0	0	0	0	0	544
Oct.	250	86	5	0	0	341	0	0	0	0	0	341
Nov.	185	36	2	0	0	223	0	0	0	0	0	223
Dec.	168	15	2	0	0	185	0	0	0	0	0	185
TOTAL	5546	1242	76	4	9	6877	0	2	59	100	161	7038

TABLE A.10

1977 INFLOW TO LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sask. R. at Hwy. 41	Red Deer R. near Bindloss	Swift Current Creek	Antelope Creek	Snakebite Creek	Total Gauged Inflow	Alkali Creek	LOCAL UNGAUGED INFLOW				Total Inflow
								West of Lemsford	Lemsford S.Landing	S.Landing To Dam	Total	
Jan.	191	13	2	0	0	206	0	0	0	0	0	206
Feb.	227	17	3	0	0	247	0	0	0	0	0	247
Mar.	242	43	2	0	0	287	0	0	0	0	0	287
Apr.	194	105	1	0	0	300	0	0	0	0	0	300
May	158	196	3	0	0	357	0	0	0	0	0	357
June	260	228	1	0	0	489	0	0	0	0	0	489
July	131	118	2	0	0	251	0	0	0	0	0	251
Aug.	200	137	1	0	0	338	0	0	0	0	0	338
Sept.	175	120	1	0	0	296	0	0	0	0	0	296
Oct.	165	107	2	0	0	274	0	0	0	0	0	274
Nov.	130	36	1	0	0	167	0	0	0	0	0	167
Dec.	139	17	1	0	0	157	0	0	0	0	0	157
TOTAL	2212	1137	20	0	0	3369	0	0	0	0	0	3369

TABLE A.11

1978 INFLOW TO LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sask. R. at Hwy. 41	Red Deer R. near Bindloss	Swift Current Creek	Antelope Creek	Snakebite Creek	Total Gauged Inflow	Alkali Creek	LOCAL UNGAUGED INFLOW				Total Inflow
								West of Lemsford	Lemsford S.Landing	S.Landing To Dam	Total	
Jan.	126	19	0	0	0	145	0	0	0	0	0	145
Feb.	159	15	1	0	0	175	0	0	0	0	0	175
Mar.	419	36	5	0.1	0.8	461	0	0	1	8	9	470
Apr.	454	280	6	0.1	0.4	740	1	7	2	4	13	753
May	926	210	2	0	0.6	1139	0	0	0	6	6	1145
June	1456	347	2	0	0	1805	0	0	0	0	0	1805
July	809	241	1	0	0	1051	0	0	0	0	0	1051
Aug.	427	189	1	0	0	617	0	0	0	0	0	617
Sept.	571	189	2	0	0	762	0	0	0	0	0	762
Oct.	466	116	2	0	0	584	0	0	0	0	0	584
Nov.	244	43	1	0	0	288	0	0	0	0	0	288
Dec.	268	29	1	0	0	298	0	0	0	0	0	298
TOTAL	6325	1714	24	0	2	8065	1	7	3	18	28	8093

A.3 PRECIPITATION

The area of Lake Diefenbaker is sufficiently large that precipitation directly on its surface contributes a substantial quantity of water. Although the quantity will not have a major impact on the total water balance for the lake it is always a positive input and ignoring it would introduce an easily avoided systematic error to water balance calculations. Therefore, a calculation based on the average monthly precipitation at the Swift Current and Elbow meteorologic stations multiplied by the average lake surface area for each month was used to estimate the inflow from this source.

There are some small inaccuracies that could enter this simplified calculation.

Lake Diefenbaker is very long and is spread over a large region so that rainfall varies widely within a given precipitation occurrence. Use of the average of Swift Current and Elbow data will reduce this error source but will not eliminate it.

Winter precipitation, being snow, drifts off the reservoir ice to some extent. The water content is probably mostly still in or near the reservoir but assuming it to be uniformly on the surface may be a small source of error. Since winter is the dry season this potential error is small.

The possibility of refining this calculation by use of more climatologic data and weighted averaging to reflect distances was considered but due to the very small component, 1 to 2 per cent of total inflows, greater detail was not justified.

Results of this calculation are tabulated in Tables A-13 to A.27 along with the storage and evaporation calculations.

A.4 RESERVOIR STORAGE

The storage capacity of Lake Diefenbaker is described on Figure 3. The storage capacity curve is based on surveys of the valley completed before the lake was filled. The curve could contain some error from the original survey and due to erosion since the lake has been in place. Such errors should be small compared to the very large surface area and although they could introduce a calculation error in individual months, over the annual cycle of rise and fall in reservoir level, errors will compensate.

In order to improve the consistency of storage calculations a table of storage versus elevation was used. This does not overcome the inaccuracies of the storage curve, it only assures that the same capacity shows up for the same elevation every time it occurs. It improves the bookkeeping and thus assists in checking accuracy of computations.

Results of the storage calculation are included in Tables A.13 to A.27.

A.5 EVAPORATION

The loss of water to the atmosphere in south and central Saskatchewan is known to be a factor in the net water supply available from surface reservoirs. Although it is a known factor, there is no way to measure evaporation.

Pan evaporation provides some indication of evaporation but the small water volume in an instrumented pan is a poor model of the vast heat storage potential of a major reservoir.

In order to better understand this phenomenon the Atmospheric Environment Service[23] of Environment Canada has operated a water temperature measurement project at Lake Diefenbaker from 1972 to 1978. These studies have established the evaporation quantities listed in Table A.12.

Unfortunately, these investigations have not produced a satisfactory method of estimating the evaporation for the period from 1969 to 1971.

The evaporation has been fairly constant from year to year with the standard deviation of the annual total evaporation being about 5 per cent of the mean. On the monthly values the deviation has been larger but not excessively. Since the potential errors of these estimates are similar in magnitude to these standard deviations, use of the mean values from the 1972 to 1978 period for the 1969 to 1971 period will be only slightly worse than using calculated values. Therefore, these mean values were used.

The monthly evaporation depth times the mean of the month end elevations was used to estimate the volume of water lost to evaporation each month. The results are included in Tables A.13 to A.27.

TABLE A.12

EVAPORATION FROM LAKE DIEFENBAKER

(mm)

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1972	60	136	135	161	151	102	52	3	800
1973	66	103	161	179	155	111	72	0	847
1974	52	125	169	157	139	107	87	37	873
1975	45	108	170	152	133	102	85	0	795
1976	111	100	140	174	157	129	74	3	888
1977	75	141	153	163	114	108	46	0	800
1978	69	113	166	181	142	118	73	3	865
Mean	68	118	156	166	141	111	69	7	838
Std. Dev.	21	16	14	11	15	10	16	14	39

TABLE A.13

1969 PRECIPITATION, EVAPORATION AND STORAGE

Month	Month End Elevation (m)	Month End Area ($m^2 \times 10^6$)	Average Area ($m^2 \times 10^6$)	Precipitation (mm)			Precip. Volume ($m^3 \times 10^5$)	Evaporation mm	Evaporation ($m^3 \times 10^6$)	Month End Storage ($m^3 \times 10^6$)	Change in Storage ($m^3 \times 10^6$)
				Swift Current	Elbow	Average					
				-	-	-	-	-	-	8096	
Dec.	553.76	393	-	37.3	35.6	36.4	14	0	0	7431	-665
Jan.	551.99	364	378.5	11.7	20.3	16.0	6	0	0	6777	-654
Feb.	550.10	344	354	23.9	10.2	17.0	6	0	0	6265	-512
Mar.	548.58	324	334	51.6	10.7	31.1	6	0	0	7442	1177
Apr.	552.02	368	346	25.9	22.4	24.1	11	68	26	7889	447
May	553.20	384	376	29.0	31.0	30.0	12	118	47	8568	679
June	554.98	409	396.5	95.8	127.3	111.5	46	156	65	9158	590
July	556.38	425	417	2.3	9.7	6.0	3	166	71	9158	0
Aug.	556.38	425	425	21.3	38.6	30.0	13	141	60	9094	-64
Sept.	556.23	425	425	64.0	80.8	72.4	30	111	47	8812	-282
Oct.	555.56	417	421	2.8	5.1	3.9	2	69	28	8408	-404
Nov.	554.58	405	411	14.5	11.7	13.1	5	7	3	7706	-702
Dec.	552.72	376	390.5								
TOTAL							154		347		-390

TABLE A.14

1970 PRECIPITATION, EVAPORATION AND STORAGE

Month	Month End Elevation (m)	Month End Area ($m^2 \times 10^6$)	Average Area ($m^2 \times 10^6$)	Precipitation (mm)			Precip. Volume ($m^3 \times 10^6$)	Evaporation mm	Evaporation ($m^3 \times 10^6$)	Month End Storage ($m^3 \times 10^6$)	Change Storage ($m^3 \times 10^6$)
				Swift Current	Elbow	Average					
Jan.	550.50	348	362	33.0	12.2	22.6	8	0	0	6912	-794
Feb.	548.76	324	336	23.9	22.4	23.1	8	0	0	6324	-587
Mar.	548.30	316	320	14.0	35.6	24.8	8	0	0	6180	-144
Apr.	550.04	344	330	40.6	30.0	35.3	12	0	0	6756	576
May	551.60	364	354	24.4	20.8	22.6	8	68	24	7285	528
June	555.40	413	388.5	214.9	91.4	153.2	60	118	43	8748	1463
July	556.69	429	421	41.4	51.8	46.6	20	156	66	9287	539
Aug.	556.38	425	427	9.4	5.3	7.4	3	166	71	9158	-128
Sept.	555.99	421	423	31.8	9.9	20.8	9	141	60	8967	-191
Oct.	555.13	409	415	30.0	21.6	25.8	11	111	46	8632	-335
Nov.	554.22	397	403	16.5	17.0	16.8	7	69	28	8268	-364
Dec.	552.51	376	386.5	23.1	25.4	24.3	9	7	3	7626	-643
TOTAL							163		341		-80

TABLE A.15

1971 PRECIPITATION, EVAPORATION AND STORAGE

Month	Month End Elevation (m)	Month End Area ($m^2 \times 10^6$)	Average Area ($m^2 \times 10^6$)	Precipitation (mm)			Precip. Volume ($m^3 \times 10^6$)	Evaporation mm	Evaporation ($m^3 \times 10^6$)	Month End Storage ($m^3 \times 10^6$)	Change in Storage ($m^3 \times 10^6$)
				Swift Current	Elbow	Average					
Jan.	550.53	348	362	23.9	58.4	41.1	15	0	0	6922	-703
Feb.	548.58	324	336	9.9	20.3	15.1	5	0	0	6265	-657
Mar.	546.84	304	314	8.4	15.2	11.8	4	0	0	5731	-533
Apr.	549.98	340	322	14.7	14.7	14.7	5	0	0	6736	1004
May	551.57	364	352	12.2	13.2	12.7	4	68	24	7274	539
June	554.52	401	382.5	72.4	89.4	80.9	31	118	45	8384	1110
July	555.62	417	409	41.4	66.3	53.8	22	156	64	8838	454
Aug.	556.11	421	419	5.6	22.1	13.8	6	166	70	9043	205
Sept.	556.05	421	421	15.2	7.4	11.3	5	141	59	9017	-26
Oct.	555.74	417	419	11.9	3.8	7.9	3	111	47	8889	-128
Nov.	554.68	405	411	13.2	5.1	9.1	4	69	28	8443	-446
Dec.	552.75	380	392.5	13.7	6.4	10.0	4	7	3	7717	-726
TOTAL							108		340		91

TABLE A.16

1972 PRECIPITATION, EVAPORATION AND STORAGE

Month	Month End Elevation (m)	Month End Area ($m^2 \times 10^6$)	Average Area ($m^2 \times 10^6$)	Precipitation (mm)			Precip. Volume ($m^3 \times 10^6$)	Evaporation mm	Evaporation ($m^3 \times 10^6$)	Month End Storage ($m^3 \times 10^6$)	Change in Storage ($m^3 \times 10^6$)
				Swift Current	Elbow	Average					
Jan.	551.02	352	366	27.9	15.2	21.6	8	0	0	7088	-629
Feb.	549.43	336	344	32.8	41.4	37.1	13	0	0	6550	-538
Mar.	548.73	324	330	8.6	2.5	5.6	2	0	0	6314	-235
Apr.	549.28	332	328	14.2	0.5	7.4	2	0	0	6498	184
May	551.54	364	348	55.6	39.6	47.6	16	60	21	7264	766
June	555.89	421	392.5	66.5	18.5	42.5	17	136	53	8953	1689
July	556.66	429	425	33.8	51.1	42.4	18	135	57	9274	321
Aug.	556.75	433	431	13.9	17.0	15.5	7	161	69	9312	38
Sept.	556.47	429	431	60.7	26.2	43.4	19	151	65	9197	-115
Oct.	556.20	425	427	10.9	10.2	10.5	4	102	44	9081	-115
Nov.	555.38	413	419	11.4	10.2	10.8	5	52	22	8735	-346
Dec.	553.46	389	401	10.9	33.0	22.0	9	3	1	7981	-754
TOTAL							120		332		264

TABLE A.17

1973 PRECIPITATION, EVAPORATION AND STORAGE

Month	Month End Elevation (m)	Month End Area ($m^2 x 10^6$)	Average Area ($m^2 x 10^6$)	Precipitation (mm)			Precip. Volume ($m^3 x 10^6$)	Evaporation mm	Evaporation ($m^3 x 10^6$)	Month End Storage ($m^3 x 10^6$)	Change in Storage ($m^3 x 10^6$)
				Swift Current	Elbow	Average					
Jan.	551.51	364	376.5	3.0	1.3	2.2	1	0	0	7254	-728
Feb.	549.95	340	352	11.9	11.7	11.8	4	0	0	6725	-528
Mar.	549.71	340	340	13.0	10.2	11.6	4	0	0	6642	-83
Apr.	551.23	360	350	81.3	41.1	61.2	21	0	0	7160	518
May	552.63	376	368	4.8	25.4	15.1	6	66	24	7672	511
June	555.04	409	392.5	31.0	43.2	37.1	15	103	40	8594	922
July	556.14	425	417	22.1	16.8	19.4	8	161	67	9056	462
Aug.	556.11	425	425	31.8	34.5	33.1	14	179	76	9043	-13
Sept.	555.68	417	421	6.1	30.0	18.0	8	155	65	8863	-180
Oct.	555.35	413	415	6.1	0.0	3.0	1	111	46	8722	-141
Nov.	554.31	393	403	33.8	33.8	33.8	14	72	29	8303	-419
Dec.	552.97	380	386.5	39.1	39.1	39.1	15	0	0	7798	-505
TOTAL							111		347		-184

TABLE A.18

1974 PRECIPITATION, EVAPORATION AND STORAGE

Month	Month End Elevation (m)	Month End Area ($m^2 \times 10^6$)	Average Area ($m^2 \times 10^6$)	Precipitation (mm)			Precip. Volume ($m^3 \times 10^6$)	Evaporation mm	Evaporation ($m^3 \times 10^6$)	Month End Storage ($m^3 \times 10^6$)	Change in Storage ($m^3 \times 10^6$)
				Swift Current	Elbow	Average					
Jan.	551.05	356	368	33.3	33.3	33.3	12	0	0	7098	-699
Feb.	549.62	380	368	32.8	32.8	32.8	12	0	0	6611	-487
Mar.	547.70	312	346	34.0	26.7	30.4	11	0	0	5993	-618
Apr.	549.74	340	326	30.2	19.6	24.8	8	0	0	6653	660
May	552.51	376	358	100.1	67.6	83.8	30	52	19	7626	973
June	555.28	413	394.5	20.1	36.6	28.3	11	125	49	8696	1071
July	556.66	429	421	45.0	22.6	33.8	14	169	71	9274	577
Aug.	556.72	433	431	130.3	73.2	101.7	44	157	68	9299	27
Sept.	556.56	429	431	18.3	23.9	21.1	9	139	60	9235	-64
Oct.	556.23	425	427	5.6	6.4	6.0	3	107	46	9094	-141
Nov.	555.44	413	419	11.2	1.3	6.2	3	87	36	8761	-334
Dec.	554.00	397	405	11.2	10.2	10.7	4	37	15	8178	-573
TOTAL							161		364		380

TABLE A.19

1975 PRECIPITATION, EVAPORATION AND STORAGE

Month	Month End Elevation (m)	Month End Area ($m^2 \times 10^6$)	Average Area ($m^2 \times 10^6$)	Precipitation (mm)			Precip. Volume ($m^3 \times 10^6$)	Evaporation mm	Evaporation ($m^3 \times 10^6$)	Month End Storage ($m^3 \times 10^6$)	Change in Storage ($m^3 \times 10^6$)
				Swift Current	Elbow	Average					
Jan.	552.21	372	384.5	10.7	22.6	16.6	6	0	0	7511	-677
Feb.	550.47	348	360	12.4	19.6	16.0	6	0	0	6901	-609
Mar.	549.43	336	342	45.7	8.4	27.1	9	0	0	6550	-352
Apr.	550.62	342	339	49.5	25.9	37.7	13	0	0	6953	404
May	553.27	384	363	48.8	20.3	34.5	13	45	16	7912	959
June	555.38	413	398.5	61.0	65.5	63.2	25	108	43	8735	822
July	556.32	425	419	38.9	38.1	38.5	16	170	71	9133	398
Aug.	556.44	429	427	77.2	51.3	64.3	27	152	65	9183	51
Sept.	556.50	429	429	36.3	24.4	30.4	13	133	57	9210	26
Oct.	556.02	421	425	33.5	33.5	33.5	14	102	43	9004	-205
Nov.	554.98	409	415	10.9	7.6	9.3	4	85	35	8568	-436
Dec.	553.79	389	399	20.6	25.9	23.2	9	0	0	8107	-461
TOTAL							155		330		-80

TABLE A.20

1976 PRECIPITATION, EVAPORATION AND STORAGE

Month	Month End Elevation (m)	Month End Area ($m^2 \times 10^6$)	Average Area ($m^2 \times 10^6$)	Precipitation (mm)			Precip. Volume ($m^3 \times 10^6$)	Evapor-ation mm	Evapor-ation ($m^3 \times 10^6$)	Month End Storage ($m^3 \times 10^6$)	Change in Storage ($m^3 \times 10^6$)
				Swift Current	Elbow	Average					
Jan.	551.78	364	376.5	19.1	25.7	22.4	8	0	0	7350	-757
Feb.	550.22	344	354	25.4	15.5	20.4	7	0	0	6819	-532
Mar.	549.74	340	342	53.0	53.3	53.3	18	0	0	6653	-166
Apr.	550.83	352	346	10.9	10.9	10.9	4	0	0	7026	373
May	553.79	376	364	27.7	19.6	23.6	9	111	40	7694	669
June	554.43	401	388.5	126 0	121.7	123.8	48	100	39	8350	655
July	555.68	417	409	50.3	49.5	49.9	20	140	57	8863	514
Aug.	556.66	429	423	41.9	9.1	25.5	11	174	74	9274	411
Sept.	556.44	429	429	4.3	7.4	5.8	3	157	67	9184	-90
Oct.	555.77	417	423	1.3	3.3	2.3	1	129	55	8902	-282
Nov.	554.77	405	411	5.3	5.1	5.2	2	74	30	8478	-423
Dec.	552.91	380	392.5	20.6	18.5	19.6	8	3	12	7775	-704
TOTAL							139		374		-332

TABLE A.21

1977 PRECIPITATION, EVAPORATION AND STORAGE

Month	Month End Elevation (m)	Month End Area ($m^2 \times 10^6$)	Average Area ($m^2 \times 10^6$)	Precipitation (mm)			Precip. Volume ($m^3 \times 10^6$)	Evaporation mm	Evaporation ($m^3 \times 10^6$)	Month End Storage ($m^3 \times 10^6$)	Change in Storage ($m^3 \times 10^6$)
				Swift Current	Elbow	Average					
Jan.	550.77	352	366	18.3	12.2	15.2	6	0	0	7005	-770
Feb.	549.71	340	346	3.8	2.8	3.3	1	0	0	6642	-363
Mar.	549.92	340	340	17.3	12.2	14.7	5	0	0	6715	73
Apr.	550.38	348	344	4.8	4.8	4.8	2	0	0	6870	155
May	550.93	356	352	117.6	128.3	122.9	43	75	26	7057	187
June	551.69	364	360	21.3	21.1	21.2	8	141	51	7316	259
July	551.84	368	366	79.9	37.8	58.4	21	153	56	7373	57
Aug.	552.08	368	368	27.7	21.3	24.5	9	163	60	7465	92
Sept.	552.36	372	370	20.8	27.4	24.1	9	114	42	7568	103
Oct.	552.54	376	374	6.1	4.1	5.1	2	108	40	7637	69
Nov.	551.54	364	368	14.2	14.2	14.2	5	46	17	7264	-373
Dec.	550.26	344	354	48.5	31.8	40.1	14	0	0	6829	-435
TOTAL							125		292		-946

TABLE A.22

1978 PRECIPITATION, EVAPORATION AND STORAGE

Month	Month End Elevation (m)	Month End Area ($m^2 \times 10^6$)	Average Area ($m^2 \times 10^6$)	Precipitation (mm)			Precip. Volume ($m^3 \times 10^6$)	Evaporation mm	Evaporation ($m^3 \times 10^6$)	Month End Storage ($m^3 \times 10^6$)	Change in Storage ($m^3 \times 10^6$
				Swift Current	Elbow	Average					
Jan.	548.95	316	330	2.7	2.7	2.7	1	0	0	6386	-443
Feb.	548.18	304	310	11.2	6.4	8.8	3	0	0	6139	-247
Mar.	548.28	305	304	10.6	20.0	15.3	5	0	0	6172	33
Apr.	549.98	332	319	53.3	18.8	36.1	11	0	0	6735	563
May	552.33	364	348	51.8	29.7	40.8	14	69	24	7553	818
June	555.02	397	381	59.4	59.4	59.4	23	113	43	8581	1028
July	556.35	417	407	14.8	44.5	29.6	12	166	68	9140	559
Aug.	556.61	421	419	18.0	17.8	17.9	8	181	76	9252	112
Sept.	556.68	422	422	54.1	51.0	52.6	22	142	60	9343	91
Oct.	556.52	418	420	11.2	11.4	11.3	5	118	50	9215	-128
Nov.	555.66	409	414	23.4	26.7	25.1	10	73	30	8850	-365
Dec.	554.72	393	401	13.2	11.4	12.3	5	3	1	8457	-393
TOTAL							119		352		1628

A.6 OUTFLOW

The largest outflow from Lake Diefenbaker occurs from Gardiner Dam into the South Saskatchewan River. The closest downstream hydrometric station is at Saskatoon (05HG001)[20], about 100 km from the dam. The effective drainage area[22] between Gardiner Dam and Saskatoon is 1254 km^2. Although the runoff from this area is small, ignoring it would introduce a systematic error. Therefore, the runoff was estimated using the average yield of two nearby streams: MacDonald Creek near Bounty (05HF005)[20], and Brightwater Creek near Kenaston (05HG002)[20]. The effective drainage area[22] of these two creeks is 153.8 km^2 and 282.3 km^2 respectively. The outflow from Gardiner Dam was estimated to be the Saskatoon flow minus this location inflow and is listed in Tables A.25 to A.34.

The outflow from Gardiner Dam occurs through hydroelectric turbines or through a gated spillway. Both of these outlets have theoratical rating data and the outflows are calculated daily. The hydrometric data was used instead of this outlet data in order to assure as much consistency of the data base as possible. A comparison of the theoretical outflows and the outflows calculated in Tables A.25 to A.34 is contained in Table A.23. This comparison shows good agreement with the average difference being under three per cent. The theoretical flows are generally lower which may indicate a slightly lower efficiency in the hydroelectric turbines than the assumed value.

TABLE A.23

COMPARISON OF GARDINER DAM THEORETICAL

RELEASES AND RELEASES CALCULATED FROM SASKATOON FLOWS

Year	Volume of Release m^3x10^6		Difference m^3x10^6	Difference %
	Theoretical	Calculated From Hydrometric Data		
1969	10200	10527	+327	+3.1
1970	6636	6809	+173	+2.5
1971	7586	7568	-18	-.2
1972	9449	9507	+58	+.6
1973	5847	6486	+539	+8.3
1974	9005	9023	+18	+.2
1975	8153	8465	+312	+3.7
1976	6439	6642	+203	+3.1
1977	3832	3910	+78	+2.0
1978	5832	5892	+60	+1.0
TOTAL	72979	74829	+1850	+2.5

The second location that water can be released from Lake Diefenbaker by gravity is through the Qu'Appelle Valley Dam to the Qu'Appelle River. This outlet is monitored by the hydrometric station on the Elbow Diversion canal at the Drop Structure (05JG006)[20]. This diversion of South Saskatchewan River water to the Qu'Appelle is listed in Tables A.25 to A.34.

The Saskatchewan Department of Agriculture diverts water from Lake Diefenbaker for agricultural, municipal, industrial and wildlife uses at the East Side Pumping Station which is measured at the Broderick Irrigation Project Main Canal below the Pumping Station (05HF007)[20]. This diversion is listed in Tables A.25 to A.34.

Minor irrigation projects around the perimeter of LakeDiefenbaker have developed over the years. Although their usage is not measured, their allocations under The Water Rights Act provide an indication of this use. Table A.24 summarizes the total licensed use of water directly from Lake Diefenbaker. The allocation by month was arbitrarily applied on the basis of typical practise.

TABLE A.24

MINOR IRRIGATION DIRECTLY FROM LAKE DIEFENBAKER

Year	Volume of Diversion $m^3 \times 10^6$					
	Annual	May	June	July	August	September
1969	0	0	0	0	0	0
1970	1	0	1	0	0	0
1971	1	0	1	0	0	0
1972	1	0	1	0	0	0
1973	1	0	1	0	0	0
1974	2	0	1	1	0	0
1975	6	1	2	2	1	0
1976	7	1	2	2	2	0
1977	8	1	2	2	2	1
1978	10	1	3	3	2	1

The total of the diversion to the Qu'Appelle, the east irrigation canal and to the minor irrigation projects was calculated in Tables A.25 to A.34 along with the total outflows.

TABLE A.25

1969 OUTFLOW FROM LAKE DIEFENBAKER

($m^3 x 10^6$)

Month	S. Sk. River S'toon	MacDonald Cresc. Near Bounty	Runoff Per km^2	Bright-water Crescent Near Kenaston	Runoff Per km^2	Average Runoff Per km^2	Local Inflow	Gardiner Dam Outflow	Diversions			Tot	Tot. Out-flow
									Qu'Ap-pelle River	Brod-erick Canal	Minor Irrig-ation		
Jan.	993	0	0	0	0	0	0	993	12	0	0	12	1005
Feb.	939	0	0	0	0	0	0	939	2	0	0	2	941
Mar.	955	0	0	0	0	0	0	955	0	0	0	0	955
Apr.	796	9.49	.062	8.73	.031	.046	58	738	0	0	0	0	738
May	836	0.95	.006	0.02	.000	.003	4	832	0	4	0	4	836
June	793	0.25	.002	0	0	.001	1	792	0	12	0	12	804
July	2023	0.12	.001	0	0	0	0	2023	7	6	0	13	2036
Aug.	618	0.05	0	0	0	0	0	618	4	2	0	6	624
Sept	477	0	0	0	0	0	0	477	11	1	0	12	489
Oct.	544	0.06	0	0	0	0	0	544	1	0	0	1	545
Nov.	701	0	0	0	0	0	0	701	6	0	0	6	707
Dec.	915	0	0	0	0	0	0	915	8	0	0	8	923
Total	10590						63	10527	51	25	0	76	10603

TABLE A.26

1970 OUTFLOW FROM LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sk. River S'toon	MacDonald Cresc. Near Bounty	Runoff Per km^2	Bright-water Crescent Near Kenaston	Runoff Per km^2	Average Runoff Per km^2	Local Inflow	Gardiner Dam Outflow	Diversions			Tot	Tot. Out-flow
									Qu'Ap-pelle River	Brod-erick Canal	Minor Irrig-ation		
Jan.	993	0	0	0	0	0	0	993	4	0	0	4	997
Feb.	788	0	0	0	0	0	0	788	4	0	0	4	792
Mar.	528	0	0	1.23	0.004	0.002	3	525	1	0	0	1	526
Apr.	347	23.07	0.150	4.26	0.015	0.083	104	243	0	0	0	0	243
May	348	3.45	0.022	0.07	0	0.011	14	334	0	1	0	1	335
June	496	0.95	0.006	0	0	0.003	4	492	0	2	1	3	495
July	518	0.86	0.006	0.04	0	0.003	4	514	0	6	0	6	520
Aug.	493	0.41	0.003	0	0	0.001	2	491	0	2	0	2	493
Sept	384	0.09	0.001	0	0	0	0	384	0	0	0	0	384
Oct.	599	0.07	0.001	0	0	0	0	599	0	0	0	0	599
Nov.	576	0	0	0	0	0	0	576	7	0	0	7	583
Dec.	870	0	0	0	0	0	0	870	7	0	0	7	877
Total	6940						131	6809	23	11	1	35	6844

TABLE A.27

1971 OUTFLOW FROM LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sk. River S'toon	MacDonald Cresc. Near Bounty	Runoff Per km^2	Bright-water Crescent Near Kenaston	Runoff Per km^2	Average Runoff Per km^2	Local Inflow	Gardiner Dam Outflow	Diversions			Tot	Tot. Out-flow
									Qu'Ap-pelle River	Brod-erick Canal	Minor Irrig-ation		
Jan.	912	0	0	0	0	0	0	912	4	0	0	4	916
Feb.	919	0	0	0	0	0	0	919	4	0	0	4	923
Mar.	852	0	0	0	0	0	0	852	0	0	0	0	852
Apr.	653	3.45	0.022	2.44	0.009	0.016	19	634	0	0	0	0	634
May	635	1.02	0.007	0.11	0	0.004	4	631	1	5	0	6	637
June	914	0.36	0.002	0.02	0	0.001	2	912	0	5	1	6	918
July	377	0.11	0.001	0	0	0	0	377	0	9	0	9	386
Aug.	218	0	0	0	0	0	0	218	1	2	0	3	221
Sept	220	0	0	0	0	0	0	220	0	4	0	4	224
Oct.	350	0	0	0	0	0	0	350	4	1	0	5	355
Nov.	636	0	0	0	0	0	0	636	6	0	0	6	642
Dec.	907	0	0	0	0	0	0	907	4	0	0	4	911
Total	7593						25	7568	24	26	1	51	7619

TABLE A.28

1972 OUTFLOW FROM LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sk. River S'toon	MacDonald Cresc. Near Bounty	Runoff Per km^2	Bright-water Crescent Near Kenaston	Runoff Per km^2	Average Runoff Per km^2	Local Inflow	Gardiner Dam Outflow	Diversions			Tot	Tot. Out-flow
									Qu'Ap-pelle River	Brod-erick Canal	Minor Irrig-ation		
Jan.	861	0	0	0	0	0	0	861	4	0	0	4	865
Feb.	771	0	0	0	0	0	0	771	2	0	0	2	773
Mar.	960	0.25	0.002	0.64	0.002	0.002	2	958	0	0	0	0	958
Apr.	803	0.30	0.002	0.58	0.002	0.002	3	800	0	0	0	0	800
May	538	0.02	0	0.04	0	0	0	538	12	7	0	19	557
June	793	0.15	0.001	0	0	0.005	1	792	10	9	1	20	812
July	1194	0	0	0	0	0	0	1194	17	14	0	31	1225
Aug.	871	0	0	0	0	0	0	871	11	11	0	22	893
Sept	625	0	0	0	0	0	0	625	2	10	0	12	637
Oct.	576	0	0	0	0	0	0	576	1	1	0	2	578
Nov.	665	0	0	0	0	0	0	665	9	0	0	9	674
Dec.	856	0	0	0	0	0	0	856	4	0	0	4	860
Total	9513						6	9507	72	52	1	125	9632

TABLE A.29

1973 OUTFLOW FROM LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sk. River S'toon	MacDonald Cresc. Near Bounty	Runoff Per km^2	Brightwater Crescent Near Kenaston	Runoff Per km^2	Average Runoff Per km^2	Local Inflow	Gardiner Dam Outflow	Diversions			Tot	Tot. Outflow
									Qu'Appelle River	Broderick Canal	Minor Irrigation		
Jan.	1011	0	0	0	0	0	0	1011	4	0	0	4	1015
Feb.	905	0	0	0	0	0	0	905	0	0	0	0	905
Mar.	609	0.14	0.001	0.002	0	0.001	1	608	1	0	0	1	609
Apr.	281	0.06	0	0.07	0	0	0	281	15	9	0	24	305
May	244	0.02	0	0	0	0	0	244	17	7	0	24	268
June	371	0	0	0	0	0	0	371	4	12	1	17	388
July	361	0	0	0.11	0	0	0	361	15	14	0	29	390
Aug.	310	0	0	0	0	0	0	310	16	14	0	30	340
Sept	453	0	0	0	0	0	0	453	1	12	0	13	466
Oct.	490	0	0	0	0	0	0	490	5	0	0	5	495
Nov.	574	0	0	0	0	0	0	574	5	0	0	5	579
Dec.	878	0	0	0	0	0	0	878	4	0	0	4	882
Total	6487						1	6486	87	68	1	156	6642

TABLE A.30

1974 OUTFLOW FROM LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sk. River S'toon	MacDonald Cresc. Near Bounty	Runoff Per km^2	Bright-water Crescent Near Kenaston	Runoff Per km^2	Average Runoff Per km^2	Local Inflow	Gardiner Dam Outflow	Diversions			Tot	Tot. Out-flow
									Qu'Ap-pelle River	Brod-erick Canal	Minor Irrig-ation		
Jan.	876	0	0	0	0	0	0	876	4	0	0	4	880
Feb.	710	0	0	0	0	0	0	710	1	0	0	1	711
Mar.	941	0	0	0	0	0	0	941	0	0	0	0	941
Apr.	898	6.70	0.044	20.23	0.072	0.058	72	826	0	0	0	0	826
May	882	0.70	0.005	0.84	0.003	0.004	5	877	0	0	0	0	877
June	1246	0.10	0.001	0.07	0	0.001	1	1245	0	5	1	6	1251
July	788	0.72	0.005	0	0	0.002	3	785	0	14	1	15	800
Aug.	583	0.04	0	0	0	0	0	583	1	5	0	6	589
Sept.	505	0	0	0	0	0	0	505	0	0	0	0	505
Oct.	406	0	0	0	0	0	0	406	0	4	0	4	410
Nov.	543	0	0	0	0	0	0	543	9	0	0	9	552
Dec.	726	0	0	0	0	0	0	726	5	0	0	5	731
Tot.	9104						81	9023	20	28	2	50	9073

TABLE A.31

1975 OUTFLOW FROM LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sk. River S'toon	MacDonald Cresc. Near Bounty	Runoff Per km^2	Bright-water Crescent Near Kenaston	Runoff Per km^2	Average Runoff Per km^2	Local Inflow	Gardiner Dam Outflow	Diversions			Tot	Tot. Out-flow
									Qu'Ap-pelle River	Brod-erick Canal	Minor Irrig-ation		
Jan.	851	0	0	0	0	0	0	851	4	0	0	4	855
Feb.	765	0	0	0	0	0	0	765	2	0	0	2	767
Mar.	613	0	0	0	0	0	0	613	0	0	0	0	613
Apr.	405	3.40	0.022	0.75	0.003	0.012	16	389	0	0	0	0	389
May	548	1.55	0.010	0.14	0	0.005	7	541	0	6	1	7	548
June	1468	0.90	0.006	0	0	0.003	4	1464	1	12	2	15	1479
July	1062	0.51	0.003	0	0	0.002	2	1060	2	17	2	21	1081
Aug.	401	0.16	0.001	0	0	0.001	1	400	5	7	1	13	413
Sept.	301	0.07	0	0	0	0	0	301	6	10	0	16	317
Oct.	566	0.05	0	0	0	0	0	566	4	0	0	4	570
Nov.	702	0	0	0	0	0	0	702	5	0	0	5	707
Dec.	813	0	0	0	0	0	0	813	5	0	0	5	818
Total	8495						30	8465	34	52	6	92	8557

TABLE A.32

1976 OUTFLOW FROM LAKE DIEFENBAKER

($m^3 x 10^6$)

Month	S. Sk. River S'toon	MacDonald Cresc. Near Bounty	Runoff Per km^2	Bright-water Crescent Near Kenaston	Runoff Per km^2	Average Runoff Per km^2	Local Inflow	Gardiner Dam Outflow	Diversions			Tot	Tot. Out-flow
									Qu'Ap-pelle River	Brod-erick Canal	Minor Irrig-ation		
Jan.	956	0	0	0	0	0	0	956	4	0	0	4	960
Feb.	799	0	0	0	0	0	0	799	1	0	0	1	800
Mar.	704	0.04	0	0	0	0	0	704	0	0	0	0	704
Apr.	466	8.96	0.058	8.78	0.031	0.044	56	410	0	0	0	0	410
May	217	1.89	0.012	0.05	0	0.006	8	209	0	7	1	8	217
June	207	0.59	0.004	10.76	0.038	0.021	26	181	0	9	2	11	192
July	207	0.39	0.003	0.33	0.001	0.002	2	205	1	12	2	15	220
Aug.	576	0.11	0.001	0	0	0	0	576	2	14	2	18	594
Sept.	560	0	0	0	0	0	0	560	7	2	0	9	569
Oct.	616	0	0	0	0	0	0	616	4	0	0	4	620
Nov.	549	0	0	0	0	0	0	549	5	0	0	5	554
Dec.	877	0	0	0	0	0	0	877	4	0	0	4	881
Total	6734						92	6642	28	44	7	79	6721

TABLE A.33

1977 OUTFLOW FROM LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sk. River S;toon	MacDonald Cresc. Near Bounty	Runoff Per km^2	Bright-water Crescent Near Kenaston	Runoff Per km^2	Average Runoff Per km^2	Local Inflow	Gardiner Dam Outflow	Diversions			Tot	Tot. Out-flow
									Qu'Ap-pelle River	Brod-erick Canal	Minor Irrig-ation		
Jan.	950	0	0	0	0	0	0	950	2	0	0	2	952
Feb.	640	0	0	0	0	0	0	640	2	0	0	2	642
Mar.	337	0.04	0	0	0	0	0	337	2	0	0	2	339
Apr.	192	0.11	0.001	0	0	0	0	192	4	0	0	4	196
May	134	0.07	0	0	0	0	0	134	10	11	1	22	156
June	136	0	0	0	0	0	0	136	10	17	2	29	165
July	132	0	0	0	0	0	0	132	9	33	2	44	176
Aug.	132	0	0	0	0	0	0	132	10	15	2	27	159
Sept.	123	0	0	0	0	0	0	123	9	11	1	21	144
Oct.	141	0	0	0	0	0	0	141	9	0	0	9	150
Nov.	414	0	0	0	0	0	0	414	4	0	0	4	418
Dec.	579	0	0	0	0	0	0	579	4	0	0	4	583
Tot.	3910						0	3910	75	87	8	170	4080

TABLE A.34

1978 OUTFLOW FROM LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	S. Sk. River S'toon	MacDonald Cresc. Near Bounty	Runoff Per km^2	Brightwater Crescent Near Kenaston	Runoff Per km^2	Average Runoff Per km^2	Local Inflow	Gardiner Dam Outflow	Diversions			Tot	Tot. Outflow
									Qu'Appelle River	Broderick Canal	Minor Irrigation		
Jan.	588	0	0	0	0	0	0	588	3	0	0	3	591
Feb.	423	0	0	0	0	0	0	423	2	0	0	2	425
Mar.	490	0.25	0.002	0.25	0.001	0.001	2	488	0	0	0	0	488
Apr.	365	0.33	0.002	0.41	0.001	0.002	2	363	0	0	0	0	363
May	149	0.05	0	0.001	0	0	0	149	2	10	1	13	162
June	629	0.01	0	0	0	0	0	629	2	22	3	27	656
July	446	0	0	0	0	0	0	446	7	28	3	38	484
Aug.	356	0	0	0	0	0	0	356	10	16	2	28	384
Sept.	613	0	0	0	0	0	0	613	10	12	1	23	636
Oct.	614	0	0	0	0	0	0	614	5	0	0	5	619
Nov.	587	0	0	0	0	0	0	587	3	0	0	3	590
Dec.	636	0	0	0	0	0	0	636	4	0	0	4	640
Total	5896						4	5892	48	88	10	146	6038

A.7 WATER BALANCE

The final set of tables in this Appendix, Tables A.35 to A.45, provide a summary of the water balance for Lake Diefenbaker. A brief listing and explanation of the column headings follows:

(a) Month: Lists the months of the year.

(b) Inflow: Lists the total inflow to Lake Diefenbaker from the South Saskatchewan River and its local tributaries.

(c) Precipitation: Lists the water reaching the reservoir surface as rain, snow or hail.

(d) Evaporation: Lists the water leaving the reservoir surface through evaporation.

(e) Diversion: Lists the sum of all the diversions of water out of the reservoir for consumptive uses.

(f) Outflow: Lists the outflow from Lake Diefenbaker to the South Saskatchewan River at Gardiner Dam.

(g) Storage: Lists the change in storage volume of the water in the lake with water withdrawals indicated as negative values.

(h) Net Impact: Lists the difference between inflow and outflow with a decrease in flow indicated as negative values.

(i) Per Cent Change: Lists the change in flow caused by Lake Diefenbaker as a percentage of the inflow.

(j) Residual: Lists the amont by which the total of all inflows, outflows and storage quantities falls to balance. It is an indication of unaccounted losses, gains or errors in the calculated water balance.

TABLE A.35

1969 SUMMARY OF WATER BALANCE FOR LAKE DIEFENBAKER

($m^3 x 10^6$)

Month	Total Inflow	Precip-itation	Evapor-ation	Diversion	Outflow S. Sask.	Change in Storage	Impact On S. Sask.	% Change S. Sask.	Residual
Jan.	271	14	0	12	993	-665	722	366	55
Feb.	229	6	0	2	939	-654	710	410	52
March	400	6	0	0	955	-512	555	239	37
April	1929	6	0	0	738	1177	-1191	38	-20
May	1433	11	26	4	832	447	-601	58	-135
June	1753	12	47	12	792	679	-961	45	-235
July	2653	46	65	13	2023	590	-630	76	-8
Aug.	630	3	71	6	618	0	-12	98	62
Sept.	348	13	60	12	477	-64	129	137	124
Oct.	340	30	47	1	544	-282	204	160	-60
Nov.	265	2	28	6	701	-404	436	264	64
Dec.	197	5	3	8	915	-702	718	464	22
Total	10448	154	347	76	10527	-390	79	101	-42

TABLE A.36

1970 SUMMARY OF WATER BALANCE FOR LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	Total Inflow	Precip-itation	Evapor-ation	Diversion	Outflow S. Sask.	Change in Storage	Impact On S. Sask.	% Change S. Sask.	Residual
Jan.	185	8	0	4	993	-794	808	537	10
Feb.	194	8	0	4	788	-587	594	406	3
March	313	8	0	1	525	-144	212	168	61
April	880	12	0	0	243	576	-637	28	-73
May	1032	8	24	1	334	528	-698	32	-153
June	2188	60	43	3	492	1463	-1696	22	-247
July	1101	20	66	6	514	539	-587	47	4
Aug.	420	3	71	2	491	-128	71	117	13
Sept.	232	9	60	0	384	-191	152	196	12
Oct.	310	11	46	0	599	-335	289	193	-11
Nov.	296	7	28	7	576	-364	280	195	-56
Dec.	217	9	3	7	870	-643	653	401	11
Total	7368	168	341	35	6809	-80	-559	92	-426

TABLE A.37

1971 SUMMARY OF WATER BALANCE FOR LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	Total Inflow	Precip-itation	Evapor-ation	Diversion	Outflow S. Sask.	Change in Storage	Impact On S. Sask.	% Change S. Sask.	Residual
Jan.	203	15	0	4	912	-703	709	449	-5
Feb.	280	5	0	4	919	-657	639	328	-19
March	295	4	0	0	852	-533	557	289	20
April	1712	5	0	0	634	1004	-1078	37	-79
May	1361	4	24	6	631	539	-730	46	-165
June	2195	31	45	6	912	1110	-1283	42	-153
July	827	22	64	9	377	454	-450	46	55
Aug.	495	6	70	3	218	205	-277	44	-5
Sept.	250	5	59	4	220	-26	-30	88	2
Oct.	270	3	47	5	350	-128	80	130	1
Nov.	289	4	28	6	636	-446	347	220	-69
Dec.	159	4	3	4	907	-726	748	570	25
Total	8336	108	340	51	7568	91	-768	91	-394

TABLE A.38

1972 SUMMARY OF WATER BALANCE FOR LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	Total Inflow	Precip-itation	Evapor-ation	Diversion	Outflow S. Sask.	Change in Storage	Impact On S. Sask.	% Change S. Sask.	Residual
Jan.	164	8	0	4	861	-629	697	525	64
Feb.	158	13	0	2	771	-538	613	488	64
March	767	2	0	0	958	-235	191	125	-46
April	821	2	0	0	800	184	-21	97	161
May	1553	16	21	19	538	766	-1015	35	-225
June	2692	17	53	20	792	1689	-1900	29	-155
July	1585	18	57	31	1194	321	-391	75	0
Aug.	917	7	69	22	871	38	-46	95	76
Sept.	561	19	65	12	625	-115	64	111	7
Oct.	489	4	44	2	576	-115	87	118	14
Nov.	373	5	22	9	665	-346	292	178	-28
Dec.	191	9	1	4	856	-754	665	448	-93
Total	10271	120	332	125	9507	-264	-764	93	-163

TABLE A.39

1973 SUMMARY OF WATER BALANCE FOR LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	Total Inflow	Precip-itation	Evapor-ation	Diversion	Outflow S. Sask.	Change in Storage	Impact On S. Sask.	% Change S. Sask.	Residual
Jan.	242	1	0	4	1011	-728	769	418	44
Feb.	245	4	0	0	905	-528	660	369	128
March	476	4	0	1	608	-83	132	128	46
April	718	21	0	24	281	518	-437	39	84
May	913	6	24	24	244	511	-669	27	-116
June	1461	15	40	17	371	922	-1090	25	-126
July	864	8	67	29	361	462	-503	42	47
Aug.	389	14	76	30	310	-13	-79	80	0
Sept.	305	8	65	13	453	-180	148	149	38
Oct.	243	1	46	5	490	-141	247	202	156
Nov.	205	14	29	5	574	-419	369	280	-30
Dec.	260	15	0	4	878	-505	618	338	102
Total	6321	111	347	156	6486	-184	165	103	373

TABLE A.40

1974 SUMMARY OF WATER BALANCE FOR LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	Total Inflow	Precip-itation	Evapor-ation	Diversion	Outflow S. Sask.	Change in Storage	Impact On S. Sask.	% Change S. Sask.	Residual
Jan.	209	12	0	4	876	-699	667	419	-40
Feb.	239	12	0	1	710	-487	471	297	-27
March	308	11	0	0	941	-618	633	306	4
April	1506	8	0	0	826	660	-680	55	-23
May	1996	30	19	0	877	973	-1119	44	-157
June	2591	11	49	6	1245	1071	-1346	48	-231
July	1308	14	71	15	785	577	-523	60	126
Aug.	642	44	68	6	583	27	-59	91	-2
Sept.	413	9	60	0	505	-64	92	122	79
Oct.	309	3	46	4	406	-141	97	131	3
Nov.	248	3	36	9	543	-334	295	219	3
Dec.	206	4	15	5	726	-573	520	352	-37
Total	9975	161	364	50	9023	380	-952	90	-319

TABLE A.41

1975 SUMMARY OF WATER BALANCE FOR LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	Total Inflow	Precip-itation	Evapor-ation	Diversion	Outflow S. Sask.	Change in Storage	Impact On S. Sask.	% Change S. Sask.	Residual
Jan.	205	6	0	4	851	-677	646	415	-33
Feb.	162	6	0	2	765	-609	603	472	-10
March	256	9	0	0	613	-352	357	239	-4
April	745	13	0	0	389	404	-356	52	35
May	1547	13	16	7	541	959	-1006	35	-37
June	2535	25	43	15	1464	822	-1071	56	-216
July	1426	16	71	21	1060	398	-366	74	108
Aug.	479	27	65	13	400	51	-79	84	23
Sept.	403	13	57	16	301	26	-102	75	-16
Oct.	400	14	43	4	566	-205	166	142	-6
Nov.	263	4	35	5	702	-436	439	267	39
Dec.	281	9	0	5	813	-461	532	289	67
Total	8702	155	330	92	8465	-80	-237	97	-50

TABLE A.42

1976 SUMMARY OF WATER BALANCE FOR LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	Total Inflow	Precip-itation	Evapor-ation	Diversion	Outflow S. Sask.	Change in Storage	Impact On S. Sask.	% Change S. Sask.	Residual
Jan.	334	8	0	4	956	-757	622	286	-139
Feb.	323	7	0	1	799	-532	476	247	-62
March	580	18	0	0	704	-166	124	121	-60
April	647	4	0	0	410	373	-237	63	132
May	1045	9	40	8	209	669	-836	20	-128
June	848	48	39	11	181	655	-667	21	-10
July	780	20	57	15	205	514	-575	26	-9
Aug.	1188	11	74	18	576	411	-612	48	-120
Sept.	544	3	67	9	560	-90	16	103	-1
Oct.	341	1	55	4	616	-282	275	181	51
Nov.	223	2	30	5	549	-423	326	246	-64
Dec.	185	8	12	4	877	-704	692	474	-4
Total	7083	139	374	79	6642	-332	-396	94	-414

TABLE A.43

1977 SUMMARY OF WATER BALANCE FOR LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	Total Inflow	Precip-itation	Evapor-ation	Diversion	Outflow S. Sask.	Change in Storage	Impact On S. Sask.	% Change S. Sask.	Residual
Jan.	206	6	0	2	950	-770	744	461	-30
Feb.	247	1	0	2	640	-363	393	259	31
March	287	5	0	2	337	73	50	117	120
April	300	2	0	4	192	155	-108	64	49
May	357	43	26	22	134	187	-223	38	-31
June	489	8	51	29	136	259	-353	28	-22
July	251	21	56	44	132	57	-119	53	17
Aug.	338	9	60	27	132	92	-206	39	-36
Sept.	296	9	42	21	123	103	-173	42	-16
Oct.	274	2	40	9	141	69	-133	51	-17
Nov.	167	5	17	4	414	-373	247	248	-110
Dec.	157	14	0	4	579	-435	422	369	-23
Total	3369	125	292	170	3910	-946	541	116	-68

TABLE A.44

1978 SUMMARY OF WATER BALANCE FOR LAKE DIEFENBAKER

($m^3 \times 10^6$)

Month	Total Inflow	Precip-itation	Evapor-ation	Diversion	Outflow S. Sask.	Change in Storage	Impact On S. Sask.	% Change S. Sask.	Residual
Jan.	145	1	0	3	588	-443	443	406	2
Feb.	175	3	0	2	423	-247	248	242	0
March	470	5	0	0	488	33	18	104	46
April	753	11	0	0	363	563	-390	48	162
May	1145	14	24	13	149	818	-996	13	-155
June	1805	23	43	27	629	1028	-1176	35	-101
July	1051	12	68	38	446	559	-605	42	48
Aug.	617	8	76	28	356	112	-261	58	-53
Sept.	762	22	60	23	613	91	-149	80	3
Oct.	584	5	50	5	614	-128	30	105	-48
Nov.	288	10	30	3	587	-365	299	204	-43
Dec.	298	5	1	4	636	-393	338	213	-55
Total	8093	119	352	146	5892	1628	-2201	73	-194

APPENDIX B

SOUTH SASKATCHEWAN RIVER

SEDIMENT DISCHARGE

B.1 INTRODUCTION

Table B.1 lists the monthly sediment loading[10] of streams in the study area.

TABLE B.1

SOUTH SASKATCHEWAN RIVER SEDIMENT DISCHARGE
10^6Kg

Year	Month	S. Sask. River at Lemsford	S. Sask. River at Saskatoon	Year	Month	S. Sask. River at Lemsford	S. Sask. River at Saskatoon
1962	Jan.	6.2	3.2	1963	Jan.	3.3	2.5
	Feb.	8.7	3.8		Feb.	6.1	7.5
	March	6.1	3.7		March	121.5	44.4
	April	304.8	846.4		April	152.4	158.7
	May	263.0	141.2		May	55.1	38.8
	June	367.4	334.8		June	1121.3	655.9
	July	281.2	178.6		July	2609.8	2888.2
	Aug.	143.1	61.6		Aug.	209.5	182.0
	Sept.	217.7	86.8		Sept.	107.0	37.3
	Oct.	11.8	21.2		Oct.	34.0	25.5
	Nov.	26.5	16.1		Nov.	13.9	10.5
	Dec.	8.9	6.1		Dec.	4.7	8.7
	Total	1645.5	1703.5		Total	4438.6	4060.0

TABLE B.1 (Continued)

SOUTH SASKATCHEWAN RIVER SEDIMENT DISCHARGE
10^6Kg

Year	Month	S. Sask. River at Lemsford	S. Sask. River at Saskatoon	Year	Month	S. Sask. River at Lemsford	S. Sask. River at Saskatoon	Swift Current Creek
1964	Jan.	4.2	9.0	1965	Jan.	1.9	5.6	
	Feb.	5.1	2.0		Feb.	3.7	.7	
	March	12.8	1.9		March	4.4	3.0	
	April	92.3	142.6		April	1534.8	52.8	
	May	1718.3	967.4		May	489.0	280.8	1.7
	June	4490.6	2174.5		June	3665.5	922.6	.1
	July	478.1	390.9		July	2408.9	981.6	.1
	August	36.3	12.7		August	259.7	122.7	0.0
	Sept.	96.6	4.5		Sept.	316.6	33.2	0.0
	Oct.	45.9	33.8		Oct.	102.0	49.0	.1
	Nov.	13.2	10.9		Nov.	21.7	6.3	
	Dec.	2.9	8.0		Dec.	11.2	10.1	
	Total	6996.3	3758.3		Total	8819.6	2468.0	2.0

TABLE B.1 (Continued)

SOUTH SASKATCHEWAN RIVER SEDIMENT DISCHARGE
10^6Kg

Year	Month	S. Sask. River at Lemsford	S. Sask. River at Saskatoon	Swift Current Creek	Red Deer River near Bindloss	S. Sask. River at Hwy. 41	Total at Alberta Border
1966	Jan.	3.5	2.4	-	-	-	-
	Feb.	4.0	4.6	-	-	-	-
	March	171.3	44.3	25.8	-	-	-
	April	966.0	384.9	1.4	-	-	-
	May	532.0	161.4	.1	66.9	398.9	465.8
	June	1454.6	698.2	.1	321.4	1560.0	1881.4
	July	1250.9	218.4	.1	1291.5	425.9	1717.4
	August	230.5	3.3	.1	118.3	18.1	136.4
	Sept.	75.4	.5	0.0	39.3	6.2	45.5
	Oct.	38.5	.6	.2	20.4	5.7	26.1
	Nov.	10.1	.5	-	3.2	3.6	6.8
	Dec.	6.2	.7	-	1.2	3.4	4.6
	Total	4743.1	1519.8	27.7			

TABLE B.1 (Continued)

SOUTH SASKATCHEWAN RIVER SEDIMENT DISCHARGE
10^6Kg

Year	Month	S. Sask. River at Lemsford	S. Sask. River at Saskatoon	Swift Current Creek	Red Deer River near Bindloss	S. Sask. River at Hwy. 41	Total at Alberta Border
1967	Jan.	5.0	39.5	-	.4	3.1	3.5
	Feb.	5.1	9.4	-	.2	3.6	3.8
	March	104.3	4.0	.3	1.4	42.5	43.9
	April	1245.9	39.2	149.4	868.8	246.4	1115.2
	May	3304.5	73.8	3.1	488.9	2835.7	3324.6
	June	6139.9	75.6	.1	938.1	4008.4	4946.5
	July	518.4	134.9	0.0	67.9	325.8	393.7
	August	45.5	4.6	0.0	28.3	7.8	36.1
	Sept.	40.8	5.0	0.0	6.0	1.9	7.9
	Oct.	9.4	3.4	0.0	6.3	2.0	8.3
	Nov.	14.8	5.7	-	4.7	7.7	12.4
	Dec.	15.0	8.8	-	2.1	2.2	4.3
	Total	11448.6	404.0	153.0	2413.0	7487.0	9900.0

TABLE B.1 (Continued)

SOUTH SASKATCHEWAN RIVER SEDIMENT DISCHARGE
10^6Kg

Year	Month	S. Sask. River at Lemsford	S. Sask. River at Saskatoon	Swift Current Creek	Red Deer River near Bindloss	S. Sask. River at Hwy. 41	Total at Alberta Border
1968	Jan.	20.6	8.9	-	1.1	6.9	8.0
	Feb.	10.4	3.3	-	.9	2.9	3.8
	March	65.2	10.9	1.8	9.9	9.9	19.8
	April	33.9	3.1	.1	14.5	4.5	19.0
	May	198.8	.3	.1	30.8	173.9	204.7
	June	1042.0	.5	0.0	233.1	728.7	961.8
	July	399.3	.4	0.0	343.0	42.1	385.1
	August	101.7	.5	0.0	100.0	7.4	107.4
	Sept.	313.9	.9	0.0	77.3	92.2	169.5
	Oct.	185.2	18.7	0.0	29.6	94.0	123.6
	Nov.	38.5	31.5	-	2.8	15.9	18.7
	Dec.	4.2	12.9	-	.6	2.4	3.0
	Total	2413.7	92.0	2.1	843.8	1180.8	2024.6

TABLE B.1 (Continued)

SOUTH SASKATCHEWAN RIVER SEDIMENT DISCHARGE
10^6Kg

Year	Month	S. Sask. River at Lemsford	S. Sask. River at Saskatoon	Swift Current Creek	Red Deer River near Bindloss	S. Sask. River at Hwy. 41	Total at Alberta Border
1969	Jan.	2.5	18.4	-	.5	2.9	3.4
	Feb.	1.6	24.0	-	.1	3.1	3.2
	March	99.1	50.0	0.0	.4	145.7	146.1
	April	3280.7	130.4	84.8	2370.0	670.6	3040.6
	May	621.6	46.1	0.0	187.8	421.4	609.2
	June	1300.0	31.8	0.0	181.0	1230.3	1421.2
	July	3828.8	1526.7	.1	1602.5	2040.6	3643.1
	August	92.2	25.0	0.0	66.5	16.2	82.7
	Sept.	222.3	17.1	0.0	263.4	2.4	265.8
	Oct.	91.9	23.9	0.0	40.1	5.6	45.7
	Nov.	32.4	34.0	-	2.2	5.6	7.8
	Dec.	9.0	20.0	-	1.1	2.2	3.3
	Total	9582.2	1947.3	85.0	4715.5	4556.4	9271.8

TABLE B.1 (Continued)

SOUTH SASKATCHEWAN RIVER SEDIMENT DISCHARGE
10^6Kg

Year	Month	S. Sask. River at Lemsford	S. Sask. River at Saskatoon	Swift Current Creek	Red Deer River near Bindloss	S. Sask. River at Hwy. 41	Total at Alberta Border
1970	Jan.	2.8	27.5	-	2.4	1.1	3.5
	Feb.	3.3	33.4	-	1.0	1.7	2.7
	March	7.8	25.8	4.0	4.0	5.2	9.2
	April	501.7	18.1	98.8	524.3	25.6	549.9
	May	362.9	8.4	.1	48.6	379.7	428.3
	June	3224.7	30.9	1.2	1567.1	2023.7	3590.8
	July	855.5	11.2	.1	707.6	243.7	951.3
	August	68.8	11.8	0.0	31.4	3.4	34.8
	Sept.	17.3	2.5	.1	10.6	1.5	12.1
	Oct.	62.9	11.5	.1	25.0	3.6	28.6
	Nov.	9.1	19.6	-	3.3	5.5	8.8
	Dec.	2.7	28.4	-	2.0	3.1	5.1
	Total	5119.5	229.0	104.4	2927.2	2697.8	5625.0

TABLE B.1 (Continued)

SOUTH SASKATCHEWAN RIVER SEDIMENT DISCHARGE
10^6Kg

Year	Month	S. Sask. River at Saskatoon	Swift Current Creek	Red Deer River near Bindloss	S. Sask. River at Hwy. 41	Total at Alberta Border
1971	Jan.	25.4	-	1.4	1.7	3.1
	Feb.	22.3	-	2.5	12.3	17.8
	March	11.9	.1	2.4	5.5	7.9
	April	8.9	95.5	3809.2	213.5	4023.7
	May	19.3	.2	111.0	570.5	681.5
	June	45.1	.1	492.0	1500.2	1992.2
	July	6.3	.1	125.7	27.3	153.0
	August	1.1	.1	53.2	3.9	57.1
	Sept.	.9	0.0	128.0	.8	128.8
	Oct.	4.5	.1	7.6	3.0	10.6
	Nov.	15.1	-	1.0	6.8	7.8
	Dec.	9.9	-	.7	1.4	2.1
	Total	170.7	96.2	4734.8	2347.0	7081.8

TABLE B.1 (Continued)

SOUTH SASKATCHEWAN RIVER SEDIMENT DISCHARGE
10^6Kg

Year	Month	Swift Current Creek	Red Deer River near Bindloss	S. Sask. River at Hwy. 41	Total at Alberta Border
1972	Jan.	-	.5	1.6	2.1
	Feb.	-	.2	2.0	2.2
	March	.6	87.2	544.6	631.8
	April	.7	220.0	165.0	385.0
	May	0.0	46.7	1287.4	1334.1
	June	0.0	691.8	2447.4	3139.2
	July	0.0	399.3	206.1	605.4
	August	0.0	92.1	52.1	144.2
	Sept.	0.0	48.4	8.6	57.0
	Oct.	0.0	8.1	4.0	12.1
	Nov.	-	2.8	3.4	6.2
	Dec.	-	.3	3.0	3.3
	Total	1.4	1597.4	4725.3	6322.7

TABLE B.1 (Continued)

SOUTH SASKATCHEWAN RIVER SEDIMENT DISCHARGE
10^6Kg

Year	Month	Red Deer R. near Bindloss	S. Sask. River at Hwy. 41	Total at Alberta Border	Year	Month	Red Deer R. near Bindloss	S. Sask. River at Hwy. 41	Total at Alberta Border
1973	Jan.	.5	2.6	3.1	1974	Jan.	.5	2.6	3.1
	Feb.	.5	3.2	3.7		Feb.	.2	5.9	6.1
	March	19.3	10.6	29.9		March	1.0	8.6	9.6
	April	483.9	15.3	499.9		April	3639.4	184.8	3824.2
	May	139.5	142.9	282.4		May	1070.2	1340.9	2411.1
	June	686.4	458.8	1145.2		June	346.1	2305.7	2651.8
	July	127.9	77.2	205.1		July	122.2	231.2	353.4
	August	72.6	3.2	75.8		August	58.4	14.7	73.1
	Sept.	35.8	1.4	37.2		Sept.	36.4	1.5	37.9
	Oct.	5.5	1.8	7.3		Oct.	13.1	1.1	14.2
	Nov.	1.0	1.4	2.4		Nov.	1.5	2.2	3.7
	Dec.	.3	2.3	2.6		Dec.	.4	1.7	2.1
	Total	1573.3	720.8	2294.1		Total	5289.6	4101.0	9390.6

TABLE B.1 (Continued)

SOUTH SASKATCHEWAN RIVER SEDIMENT DISCHARGE
10^6Kg

Year	Month	Red Deer R. near Bindloss	S. Sask. River at Hwy. 41	Total at Alberta Border	Swift Current Creek	Year	Month	Red Deer R. near Bindloss	S. Sask. River at Hwy. 41	Total at Alberta Border
1975	Jan.	1.5	.5	2.0	-	1976	Jan.	.1	10.9	11.0
	Feb.	1.3	1.3	2.6	-		Feb.	.1	8.4	8.5
	March	.8	3.5	4.3	-		March	31.9	25.2	57.1
	April	578.7	256.8	835.5	10.8		April	139.4	43.8	182.2
	May	344.1	1025.5	1369.6	2.2		May	17.2	544.5	561.7
	June	91.9	5525.7	6627.6	.2		June	110.1	102.0	212.1
	July	68.0	614.9	682.9	-		July	120.2	76.4	196.6
	August	35.2	16.0	51.2	-		August	447.4	473.8	921.1
	Sept.	15.5	5.2	20.7	-		Sept.	14.4	11.2	25.6
	Oct.	5.0	5.1	10.1	-		Oct.	5.8	2.1	7.9
	Nov.	2.4	4.3	5.7	-		Nov.	.8	1.5	2.3
	Dec.	.2	5.2	5.4	-		Dec.	.2	1.1	1.3
	Total	1144.7	7464.0	8608.7	-		Total	887.7	1300.8	2188.5

APPENDIX C

QU'APPELLE RIVER DIVERSIONS

C.1 INTRODUCTION

Tables C.1 to C.10 list the diversion from Lake Diefenbaker to the Qu'Appelle River and provide a comparison to the flow of the Qu'Appelle River at three downstream locations:

1. Qu'Appelle River above Buffalo Pound Lake;
2. Qu'Appelle River below Craven Dam; and
3. Qu'Appelle River at Tantallon for the period 1969 to 1974 and near Welby for the period 1975 to 1978.

The Qu'Appelle River diversion flows are measured at a hydrometric station named Elbow Diversion Canal at Drop Structure (05JG006).[20]

TABLE C.1

1969 IMPACT ON QU'APPELLE RIVER FLOWS

($m^3 \times 10^6$)

Month	Diversion Qu'Appelle	Qu'Appelle River above Buffalo Pd. L.	%Impact above Buffalo Pd. L.	Qu'Appelle River at Craven	%Impact at Craven	Qu'Appelle River at Tantallon	%Impact at Tantallon
Jan.	4	15	27	1	400	4	100
Feb.	2	7	29	3	67	4	50
Mar.	0	0	0	1	0	6	0
Apr.	0	32	0	86	0	56	0
May	0	0	0	46	0	81	0
June	1	0	-	12	8	61	2
July	2	7	29	11	18	37	6
Aug.	5	3	140	11	45	5	100
Sept.	6	10	60	8	75	8	75
Oct.	4	1	400	12	33	15	27
Nov.	5	6	83	11	45	14	36
Dec.	5	8	63	9	56	11	45
Total	34	89	38	211	16	302	11

TABLE C.2

1970 IMPACT ON QU'APPELLE RIVER FLOWS

($m^3 \times 10^6$)

Month	Diversion Qu'Appelle	Qu'Appelle River above Buffalo Pd. L.	%Impact above Buffalo Pd. L.	Qu'Appelle River at Craven	%Impact at Craven	Qu'Appelle River at Tantallon	%Impact at Tantallon
Jan.	4	6	67	10	40	9	44
Feb.	1	2	50	5	20	9	11
Mar.	0	7	0	6	0	9	0
Apr.	0	21	0	60	0	43	0
May	0	3	0	73	0	72	0
June	0	2	0	49	0	76	0
July	1	2	50	14	7	59	2
Aug.	2	1	200	11	18	36	6
Sept.	7	0	-	17	41	10	70
Oct.	4	0	-	20	20	22	18
Nov.	5	6	83	19	26	26	19
Dec.	4	7	57	11	36	17	24
Total	28	57	49	294	10	389	7

TABLE C.3

1971 IMPACT ON QU'APPELLE RIVER FLOWS

($m^3 \times 10^6$)

Month	Diversion Qu'Appelle	Qu'Appelle River above Buffalo Pd. L.	%Impact above Buffalo Pd. L.	Qu'Appelle River at Craven	%Impact at Craven	Qu'Appelle River at Tantallon	%Impact at Tantallon
Jan.	2	3	67	10	20	11	18
Feb.	2	6	33	7	29	8	25
Mar.	2	0	-	11	18	14	14
Apr.	4	14	29	92	4	63	6
May	10	1	1000	20	50	95	11
June	10	2	500	0	-	50	20
July	9	0	-	1	900	8	113
Aug.	10	0	-	5	200	2	500
Sept.	9	0	-	5	180	5	180
Oct.	9	3	300	21	43	17	53
Nov.	4	6	67	10	40	16	25
Dec.	4	5	80	17	24	12	33
Total	75	40	188	205	37	301	25

TABLE C.4

1972 IMPACT ON QU'APPELLE RIVER FLOWS

($m^3 \times 10^6$)

Month	Diversion Qu'Appelle	Qu'Appelle River above Buffalo Pd. L.	%Impact above Buffalo Pd. L.	Qu'Appelle River at Craven	%Impact at Craven	Qu'Appelle River at Tantallon	%Impact at Tantallon
Jan.	4	3	133	11	36	13	31
Feb.	2	3	67	7	29	12	17
Mar.	0	3	0	13	0	21	0
Apr.	0	3	0	17	0	58	0
May	12	11	109	1	1200	15	80
June	10	6	167	4	250	5	200
July	17	15	113	7	243	2	850
Aug.	11	11	100	8	138	4	275
Sept.	2	4	50	7	29	6	33
Oct.	1	1	100	7	14	8	13
Nov.	9	10	90	10	90	8	113
Dec.	4	6	67	5	80	11	36
Total	72	75	96	97	74	164	44

TABLE C.5

1973 IMPACT ON QU'APPELLE RIVER FLOWS

($m^3 \times 10^6$)

Month	Diversion Qu'Appelle	Qu'Appelle River above Buffalo Pd. L.	%Impact above Buffalo Pd. L.	Qu'Appelle River at Craven	%Impact at Craven	Qu'Appelle River at Tantallon	%Impact at Tantallon
Jan.	4	3	133	4	100	16	25
Feb.	0	1	0	4	0	8	0
Mar.	1	2	50	7	14	11	9
Apr.	15	15	100	8	188	4	375
May	17	17	100	8	213	4	425
June	4	5	80	9	44	9	44
July	15	13	115	6	250	10	150
Aug.	16	13	123	5	320	4	400
Sept.	1	3	33	4	25	2	50
Oct.	5	5	100	9	56	4	125
Nov.	5	4	125	7	71	4	125
Dec.	4	3	133	7	57	8	50
Total	87	84	104	78	112	84	104

TABLE C.6

1974 IMPACT ON QU'APPELLE RIVER FLOWS

($m^3 \times 10^6$)

Month	Diversion Qu'Appelle	Qu'Appelle River above Buffalo Pd. L.	%Impact above Buffalo Pd. L.	Qu'Appelle River at Craven	%Impact at Craven	Qu'Appelle River at Tantallon	%Impact at Tantallon
Jan.	4	3	133	5	80	8	50
Feb.	1	1	100	3	33	7	14
Mar.	0	0	-	4	0	7	0
Apr.	0	59	0	125	0	57	0
May	0	14	0	132	0	183	0
June	0	1	0	96	0	158	0
July	0	0	-	71	0	89	0
Aug.	1	1	100	62	2	70	1
Sept.	0	1	0	50	0	62	0
Oct.	0	0	-	40	0	55	0
Nov.	9	8	113	37	24	43	21
Dec.	5	6	83	28	18	31	16
Total	20	94	21	653	3	770	3

TABLE C.7

1975 IMPACT ON QU'APPELLE RIVER FLOWS

($m^3 \times 10^6$)

Month	Diversion Qu'Appelle	Qu'Appelle River above Buffalo Pd. L.	%Impact above Buffalo Pd. L.	Qu'Appelle River at Craven	%Impact at Craven	Qu'Appelle River at Tantallon	%Impact at Tantallon
Jan.	4	3	133	21	19	25	16
Feb.	2	2	100	14	14	21	10
Mar.	0	0	-	14	0	20	0
Apr.	0	9	0	49	0	80	0
May	0	1	0	99	0	211	0
June	0	2	0	52	0	119	0
July	7	1	700	45	16	61	11
Aug.	4	4	0	35	11	39	10
Sept.	11	6	183	31	35	43	26
Oct.	1	5	20	23	4	40	3
Nov.	6	3	200	18	33	34	18
Dec.	8	3	267	12	67	20	40
Total	51	39	131	414	12	713	7

TABLE C.8

1976 IMPACT ON QU'APPELLE RIVER FLOWS

($m^3 \times 10^6$)

Month	Diversion Qu'Appelle	Qu'Appelle River above Buffalo Pd. L.	%Impact above Buffalo Pd. L.	Qu'Appelle River at Craven	%Impact at Craven	Qu'Appelle River at Tantallon	%Impact at Tantallon
Jan.	4	3	133	8	50	17	24
Feb.	4	1	400	7	57	15	27
Mar.	1	7	14	18	6	16	6
Apr.	0	11	0	157	0	28	0
May	0	0	-	57	0	189	0
June	0	1	0	54	0	108	0
July	0	0	-	46	0	73	0
Aug.	0	1	0	34	0	45	0
Sept.	0	7	0	31	0	23	0
Oct.	0	4	0	26	0	31	0
Nov.	7	4	175	17	41	25	28
Dec.	7	4	175	11	64	22	32
Total	23	43	53	434	5	840	3

TABLE C.9

1977 IMPACT ON QU'APPELLE RIVER FLOWS

($m^3 \times 10^6$)

Month	Diversion Qu'Appelle	Qu'Appelle River above Buffalo Pd. L.	%Impact above Buffalo Pd. L.	Qu'Appelle River at Craven	%Impact at Craven	Qu'Appelle River at Tantallon	%Impact at Tantallon
Jan.	4	3	133	6	67	15	27
Feb.	4	3	133	5	80	10	40
Mar.	0	3	0	6	0	9	0
Apr.	0	4	0	1	0	6	0
May	1	7	14	4	25	8	13
June	0	9	0	5	0	8	0
July	0	6	0	4	0	6	0
Aug.	1	7	14	3	33	2	50
Sept.	0	8	0	2	0	1	0
Oct.	4	9	44	3	133	7	57
Nov.	6	4	150	4	150	13	46
Dec.	4	3	133	4	100	6	67
Total	24	66	36	49	49	91	26

TABLE C.10

1978 IMPACT ON QU'APPELLE RIVER FLOWS

($m^3 \times 10^6$)

Month	Diversion Qu'Appelle	Qu'Appelle River above Buffalo Pd. L.	%Impact above Buffalo Pd. L.	Qu'Appelle River at Craven	%Impact at Craven	Qu'Appelle River at Tantallon	%Impact at Tantallon
Jan.	3	3	100	3	100	2	150
Feb.	2	2	100	2	100	1	200
Mar.	0	1	0	4	0	2	0
Apr.	0	4	0	9	0	19	0
May	2	2	100	2	100	14	14
June	2	2	100	1	200	11	18
July	7	6	117	1	700	7	100
Aug.	10	9	111	1	1000	3	333
Sept.	10	10	100	1	1000	1	1000
Oct.	5	5	100	0	-	5	100
Nov.	3	4	75	4	75	11	27
Dec.	4	3	133	5	80	4	100
Total	48	51	94	34	141	80	60

POOR

QUALITY

ORIGINAL